RAIL FAILURES

RAIL FAILURES
FOR
THE TRACKMAN

WITH NOTES ON

RAIL SPECIFICATIONS, RAIL MANUFACTURE, AND RAIL SECTIONS.

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PREFACE.

The causes of Rail Failures and the remedies therefor, constitute a problem which requires the most careful study by every employe in the Maintenance and Operating Departments of any railroad, from the Section Foreman to the Chief Engineer and General Manager.

The elimination of Rail Failures, in a commercially practical way, is the subject of careful investigation by the manufacturers and by the railroads. This investigation has been carried on, for the railroads, by the American Railway Engineering Association, the details being handled by its Committee on Rail.

The safety of the traveling public and of the employe is involved in this question.

To study it intelligently one must have at least an elementary knowledge of the process of rail manufacture, and of the specifications under which a rail of good quality can be delivered, as well as a knowledge of what constitutes *good practice* in Maintenance and Operation.

It is the aim of this book to give the Trackman sufficient information on Rail Manufacturing Practice to enable him—

1. To properly classify each failure,
2. To report intelligently on any internal or external defects disclosed by careful examination of the fractured surfaces,
3. To make proper entry of above on his rail failure report, together with data concerning track and equipment conditions.

It is of the utmost importance that all the above details be reported in full as soon as the failure is discovered; for while the pieces of the broken rail rail can be examined in the laboratory and conclusions as to its internal structure drawn, any time after the failure, the other conditions which may have influenced that failure may change immediately, and no reliable data concerning them other than shown on the Foreman's report, can afterwards be obtained.

Next to a proper description of the kind of failure and the conditions surrounding same, it is important to see that the Heat Number, Rail Letter, and Ingot Number (where used) be correctly given. Where the rail is rusted it should be carefully cleaned off and the Foreman should satisfy himself that he has obtained the correct information.

When the Foreman's report is fully and accurately made out it will be found in the majority of cases that further examination of the broken rail is unnecessary; otherwise, a special representative of the Engineering Department must make an investigation of conditions.

Too often it is found that the wrong heat number has been reported, causing delay until further examination can be made, and this could easily be avoided by the exercise of a little care on the part of the Foreman.

Rail failures are more numerous in the winter months, and during severe cold weather the Trackman should be especially watchful for signs of failures.

Probably every railroad has careful analyses and statistics made of all rail breakages that have been reported, but in many cases sufficient stress is not laid on the absolute necessity for obtaining from the Section Foreman a complete report covering EVERY RAIL THAT FAILS on his section.

It is as essential to have statistics from lines that accept rails made under Manufacturer's Specifications as from lines using other specifications, and whose inspectors see that the material furnished complies therewith.

The art of steel rail manufacture is not yet perfect; no one mill makes all good rails, and none makes all imperfect rails.

The quality of rails has undoubtedly improved in recent years, due to

improvements in rail sections,
improvements in mill practice,
more uniform chemical composition, and
thorough inspection.

Furthermore, the number of rails that fail annually compared to the total number in service, is very small.

These improvements are due in large part to the work of the American Railway Engineering Association, backed by the American Railway Association.

One of the most important objects of compiling rail failure statistics is to ascertain which manufacturers furnish, consistently from year to year, rails that give good service.

Nearly every railroad is in a position to make a choice between two or more mills when placing rail orders, and it is proper to place them where they can get the best material at the general market price.

Nearly all rail manufacturers will replace, free of charge, all defective rails found during the first five years of service.

The Trackman should not feel that the sending in of a great many rail failure reports is a reflection on his maintenance methods. The Trackman is ranked among the most faithful and industrious

employes of the railroad, and it may be said that in all cases he does the best he can with, and gets the best possible results out of, the material supplied him. In times of general financial depression his supplies are, too often, inadequate.

Nevertheless, he must bear in mind that he can render valuable assistance to the cause of *Safety First* as applied to Rail Failures, by being constantly on the alert for signs of impending failures, by removing such rails from service prior to total failure, and by reporting promptly and fully on every case.

By this means only will the Chief Engineer be enabled to determine the cause of the failure, whether due to defective rail, defective equipment or operation, or to inferior maintenance, and be in a position to apply the proper remedy.

A. L. DAVIS.

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This book is largely a compilation, modified and supplemented by the writer's views and experience.

The following sources of information were drawn upon:

Data on *Rail Failures* was obtained largely from papers, appearing in the columns of the RAILWAY AGE GAZETTE, by Mr. W. C. Cushing, Dr. P. H. Dudley, Capt. Robt. W. Hunt, Mr. Robert Job, Mr. J. P. Snow, Mr. Bradley Stoughton and Mr. F. A. Weymouth.

Data on *Properties and Manufacture of Iron and Steel* from the works of Mr. H. P. Tiemann and Mr. H. H. Campbell.

The reader should guard against accepting the data, in the form given herein, as expressing the exact views of the individuals mentioned above.

I am especially indebted to Mr. Chas. W. Gennet, Jr., for many valuable suggestions, as well as for the data contained in Chapters VIII and XXIV.

A. L. DAVIS.

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PART I
MANUFACTURE OF IRON

CHAPTER I.

IRON AND IRON ORES

Iron and steel are metallic mixtures, the chief ingredient being the element iron, of which they contain from 93 per cent to 99 per cent. The difference between iron and steel is principally due to the composition and proportion of the remaining ingredients. Iron is rarely found in the metallic condition; but, in combination with oxygen, as oxide of iron, it exists in large quantity. Iron ores contain from 25 per cent to 70 per cent of iron, the balance being oxygen, phosphorus, sulphur, silica, and other impurities.

The earthy material and impurities, always found associated with any metallic ore, is called the *gangue.*

If the ores contain less than 40 per cent iron they must first be *concentrated,* that is, part of the gangue removed; if less than 25 per cent, the cost of smelting is so great that they are not of commercial value.

Lake Superior, Wyoming and New Mexico ores contain from 55 per cent to 60 per cent, Cuban ores average about 55 per cent, while Alabama ores average only about 35 per cent, iron.

The principal commercial ore is the anhydrous ferric oxide, which varies in color from a brilliant black to a brick red, and is ordinarily known as hematite, red hematite, or red iron ore.

Other commercial ores are:

Hydrated ferric oxide, in color, from a light yellow to a dark brown, may be soft and pul-

verulent or hard and compact, and known as brown hematite, brown iron ore, bog iron ore.

Magnetic oxide, a black, hard mineral, occurring in large masses or granulated, known as magnetic iron ore, black iron sand, etc.

Carbonate, occurs usually in granular masses of a gray or brown color, known as spathic iron ore, brown ore, etc.

Iron ore is *smelted* (melted down) in a blast furnace, the metal obtained being commercially known as *pig iron.* It contains about 93 per cent of pure iron, 3 per cent to 5 per cent of carbon (pure coal), some silicon, phosphorus, sulphur, etc.

From this pig iron all steel is made.

Pig iron is also used in foundries for the manufacture of iron castings, by melting it in a cupola; this does not change its composition, but it gives the metal a closer grain and some increase in strength.

Pig iron (or cast iron) has a grayish-white lustrous appearance, does not harden appreciably on quenching, and is brittle with little, if any, ductility.

Pig iron and cast iron contain about 4 per cent of carbon, wrought iron only a trace of it, while steel is between these two extremes.

CHAPTER II.

THE BLAST FURNACE AND THE MANUFACTURE OF PIG IRON

The blast furnace is a brick structure, circular in section, from 80 to 100 feet in height, and can manufacture from 300 to 600 tons of pig iron per day.

It is built of fire-brick and in two parts, the upper part resting on columns, the lower part resting directly on the foundations. The upper portion is encased in steel plates, and water circulates around the lower portion, in pipes, or flows down the outside.

It is used for smelting iron ore to obtain pig iron, and its name arises from the fact that a blast of hot air is blown in at the bottom of the furnace, to burn the fuel which supplies the heat, as well as the carbon necessary for the reduction (deoxidation) and carburization of the ore, and to make the iron and slag molten.

The furnace is continuous in operation, the solid raw materials being charged at the top, and the molten iron and slag being tapped out at the bottom at intervals.

In order to separate the gangue from the iron it is necessary to use a *flux*, that is, a material that will combine with the gangue and produce a suitable slag by (a) making it sufficiently fusible, and (b) combining with the impurities in the gangue and thus preventing them from entering or remaining in the iron.

The principal flux used in blast furnaces making pig iron is *limestone* or lime.

The heat in the furnace is derived from the combustion of *coke*.

The three materials, *ore, limestone and coke* form what is known as the *charge*, or *burden*.

Blast Furnace.

The charge is put in at the top of the furnace at nearly regular intervals, and the height of the materials in the furnace is maintained at a constant level called the *stock line.*

At a point near the bottom of the furnace is a hole for tapping the molten iron, and a little higher up and to one side, is a hole for tapping the molten slag.

The slag is tapped out at more frequent intervals than the iron, is run directly into ladles, and carried away; it is used for ballast, and for the manufacture of cement.

The iron is led through sand troughs or *runners* to the pig bed if it is to be sand cast, or into ladles, and is carried away to be used in the manufacture of steel, or to be cast into pigs in a pig machine.

The small amount of slag which comes out of the iron hole floats on top of the iron, and is diverted into a side trough by a *skimmer.*

A modern plant requires, in addition to the furnace proper, blowing engines for furnishing air for the blast, stoves for preheating the blast, appliances for charging the raw material, and sometimes a cast-house, or pig machine.

The top of the furnace is so constructed that the charge can be put in without permitting the escape of gas from the furnace.

The furnace gas is taken off at the top of the furnace, the dust removed from it, and after further purification it is used for heating the stoves, burning under boilers, or as the fuel for direct combustion engines.

The stoves for heating the blast are circular in section, are about as high as the furnace, and consist of a steel shell lined with fire-brick in such a way

as to form a number of flues or passages. The gas is introduced and burned at the bottom, and the products of combustion go out at the top. After the fire-bricks have been heated to the proper temperature the gas is shut off, and the air for the blast is forced through in the opposite direction. A large blast furnace generally has four stoves, three of which are being heated while the fourth is heating the blast.

As the product of the blast furnace varies considsiderably in its composition, it is customary, before using it in the manufacture of steel, to first put it in a *mixer*. The mixer is a huge pot-shaped vessel, capable of holding from 250 to 600 tons of molten pig iron; as a rule, the larger the mixer the greater the uniformity obtained, and the easier is the heat retained.

Where the hot iron from the blast furnace is not placed in mixers, nor used directly in the steel-making furnace, the cold pig iron used for making steel is first melted in large cupolas.

PART II

MANUFACTURE OF RAIL STEEL.

INTRODUCTION.

The manufacture of steel is the process by which the proper proportion of carbon is obtained in the iron.

Steel used in making rails is manufactured by taking pig iron and burning the excess carbon out of it.

Steel which owes its physical properties chiefly to various percentages of carbon, is known as ordinary steel or *carbon steel.*

All rail manufactured in this country is made by either the straight *Bessemer* or *Open Hearth* processes, or by a combination of those two, known as *Duplex* process.

In the *Duplex* process the steel is started in a Bessemer converter and finished in an Open Hearth furnace.

Some rail is being made by what is known as the *Triplex* process, in which the steel is started in a Bessemer converter and passed serially through two Open Hearth furnaces, but this process is not yet well developed.

High grade steels are being made in considerable quantity by means of the *Electric Furnace,* but this method is not yet used for manufacture of rail steel, except experimentally.

In the Bessemer process, as practiced in the United States, it is impossible to reduce the proportion of phosphorus below that existing in the original charge of pig iron; while in the Open Hearth process, phosphorus can be left at any desired proportion or almost entirely eliminated.

The higher the phosphorus content the more brittle is the steel; as the toughness of the steel is increased by cutting down the proportion of phosphorus, and as the supply of iron ores which contain a small amount of that element is becoming exhausted, the Open Hearth and Duplex processes are rapidly taking the place of the straight Bessemer process.

With a low phosphorus content it is safe to use a higher proportion of carbon. Hence, we get a rail with a higher elastic limit, with increased hardness and capacity for wear.

Open Hearth rails are, however, subject to the same general defects which may be found in Bessemer rails, and, therefore, require equal care in process of manufacture. However, the rail failure statistics of the American Railway Engineering Association, show that the rate of failure for Bessemer steel rails is much higher than that of Open Hearth steel rails of same section and under similar conditions. Both show almost same tensile strength under a static load, but Bessemer steel is weaker under a rapidly applied stress, especially in cold weather.

On the other hand, Bessemer rails when carefully made, may give better results in service than Open Hearth rails in which the same amount of care in manufacture has not been exercised.

Some steel makers claim that the Bessemer process is cheaper than the Open Hearth process, and it is still favored by a few mills which have large bodies of low phosphorus ores in sight.

Experience indicates that Open Hearth steel rails are more subject to pipe and segregation than Bessemer steel rails—because of larger ingots, and because the size of the heat prevents slow casting; on account of low phosphorus content in the former the

danger of segregation is lessened, but the higher carbon content tends to increase segregation of that element.

Modern practice, in order to produce more tonnage, has been in the direction of larger heats of steel, larger ingots, fewer passes through the rolls, and more rapid reduction of cross-section.

Whereas, formerly, thirty passes were required to produce a 60-lb. rail, 100-lb. rails are now produced in fifteen to eighteen passes.

In the past few years, however, there has been an undoubted improvement in quality at most of the mills, due to improved mill practice.

The steel manufacturers are now directing their efforts towards adopting such new methods as may be commercially practicable, for bettering their product, and some of the mills have rebuilt all, or portions, of their plants with this end partly in view.

Some mills now make furnace and ladle additions in liquid (instead of solid) form, thus insuring quick reaction and thorough mixture.

One or two mills are experimenting with the *sinkhead process* of casting ingots, thus keeping all pipe and segregation in the upper part of the ingot so that it can readily be removed in the usual discard.

The use of greater amounts of Silicon and Aluminum in the ladle and ingot molds is becoming general. Bottom pouring of ingots is practiced in some cases. Some mills are using a special wash for the inside surface of the ingot molds.

Practically all the mills are giving more particular attention to special control of the heats.

CHAPTER III.

STEEL AND ITS CONSTITUENTS.

The word *Steel* covers a multitude of mixtures which are very different from each other in their chemical as well as their physical qualities.

Steel consists almost wholly of the element *Iron,* with something like 2 per cent or more of other elements, depending upon the use for which the steel is designed.

Of the other elements some serve a useful purpose, while others do not, the latter being called impurities.

One of the aims of good steel makers is to eliminate as much of the impurities as is commercially practicable, and to have the remaining constituents distributed evenly throughout the metal so as to give a uniform structure.

The useful elements ordinarily existing in rail steel are IRON, CARBON, MANGANESE, SILICON, and in addition frequent use is made of Nickel, Chromium, Aluminum, Titanium and Vanadium.

The usual impurities are SULPHUR, PHOSPHORUS, SLAG and GASES.

Article 1.—USEFUL ELEMENTS.

IRON—This is a metal with which everyone is familiar, and sufficient attention has already been drawn to it in previous chapters.

CARBON—Next to iron, carbon is the most important element in rail steel.

Familiar forms of the element carbon are *coal, graphite, soot, coke, charcoal.*

The elastic limit and tensile strength of the steel is in direct proportion to the amount of carbon content up to a total proportion of 1 per cent of the mixture, while the ductility decreases.

Soft boiler steel plate may contain but .06 per cent, steel rails from .40 per cent to .80 per cent (according to size), steel springs about 1.00 per cent, and razor steel about 1.25 per cent carbon.

Steel (or iron) which is very low in carbon can easily be welded but it cannot be tempered; when carbon is above .33 per cent welding is more difficult.

Steel with carbon above .40 per cent can be tempered; that is, hardened by quenching in water (or other liquid) from a red heat, and according to the proportion of carbon, becomes very hard, and can be used for tools, such as saws, files, chisels, drills, cutlery, etc.

Other ingredients, such as Nickel, Tungsten, Manganese, etc., are sometimes used to influence the hardness; steels containing such elements are often referred to as *Special Steels.*

MANGANESE—Usually found in combination with oxygen and in conjunction with iron. The pure metal has a grayish-white color, with a slight tinge of red, and is hard and brittle.

Next to carbon it is the most important constituent of steel. It has a stronger affinity for oxygen and sulphur than has iron, and in ordinary amounts it will remove oxygen existing in the steel either as a gas or in direct combination as oxide.

Manganese is added to steel for two reasons:

1. To unite with the oxygen.
2. To make the metal more malleable and ductile when hot, so it will roll more readily and conform better to the desired shape.

Its addition to the metal is made in the form of an alloy with iron, which when about 15 per cent manganese and 85 per cent iron is called *spiegel* or *spiegeliesen,* and when 80 per cent manganese and 20 per cent iron is called *ferro-manganese.*

In ordinary steel the manganese varies from about .50 per cent to 1.10 per cent. Below .40 per cent the removal of the oxygen does not seem to be sufficiently thorough; above 1.10 per cent and up to about 6 per cent or 7 per cent the hardness and the brittleness of the steel increase so rapidly that the material is of little commercial value; while above 7 per cent and up to 10 per cent it becomes absolutely worthless. Above 10 per cent and up to about 15 per cent a curious reversal takes place, the metal becoming very hard and tough after quenching in water from 1600 degrees F.; this composition is called *manganese steel.* Above this point the metal becomes more brittle again.

Manganese also tends to neutralize the effect of sulphur and prevent *red-shortness;* that is, tendency to crack while being worked at a red heat.

SILICON—It is always found combined with oxygen as silica (sand) or a silicate.

It combines with iron to form iron-silicide. It is always a constituent of pig iron; if higher than about 6 per cent it is called *ferro-silicon,* in which form it is valuable as a deoxidizer.

In ordinary steel it is usually under .30 per cent; in steel castings it is generally under .25 per cent; while for certain purposes it may go as high as 1.00 per cent.

In small proportions it hardens the steel, and also tends to prevent unsound metal. It has a remarkably strong affinity for oxygen, and in this particular lies its usefulness in steel. After the manganese has done its duty silicon is added to remove the remaining gases.

There is good reason to presume that the higher the silicon in steel, within reasonable limits, the more is the wearing quality of the steel increased.

Article 2.—IMPURITIES.

SLAG—Sometimes called *cinder*, is the molten substance, other than the metal under treatment, consisting of acid or basic oxides which may be composed

(a) In Smelting operations, of the gangue of the ore combined with some fluxing material (usually lime) added to render it fusible and easily separated from the metal, or

(b) In purifying processes, of substances (usually lime and iron oxides) introduced for the purpose of affecting or assisting in the purification.

As a result of the methods by which steel is manufactured, it is obvious that the liquid metal coming from the furnace is permeated with particles of slag which, because of being lighter than the mother liquid, rapidly seek the top in an effort to escape; notwithstanding, unless great precautions are taken, particles of Iron, Manganese and Silicon oxides are often found in the finished steel.

PHOSPHORUS—It is the most undesirable impurity which occurs in steel. It is usually limited to .10 per cent in Bessemer and to .04 per cent in Open Hearth steel.

It has a greater hardening effect than either carbon or silicon, and reduces the power of the steel to resist impact.

It makes steel *cold-short;* that is, brittle at atmospheric temperatures.

An amount of phosphorus, so small, that with proper proportion to carbon, both toughness and hardness are insured, is not objectionable.

SULPHUR—It is found both free and combined. It combines with oxygen and manganese to form

oxides and sulphides, which are almost entirely, if not quite, insoluble in steel, thus breaking up the continuity of the structure.

When present in steel in undesirable amounts it makes the metal *red-short;* that is, to crack while being worked at rolling temperatures; this produces, in the case of rails, a large number of second quality and scrap rails.

OXYGEN—A gas which forms one-fifth (by volume) of the air. Combined with iron it forms *iron-oxide.* Familiar forms of iron-oxide are iron ore, rust, and the scale which forms on an iron or steel bar in cooling after removal from a furnace or forge.

Many deleterious effects are laid to the presence of oxygen in steel, and steel containing over a certain per cent of oxygen is usually considered undesirable.

NITROGEN—A gas which forms four-fifths of air. It is often found in steel, and its ill effects are the subject of careful investigation.

CHAPTER IV.

BESSEMER PROCESS OF MAKING RAIL STEEL.

This process consists of blowing air through molten iron contained in a suitable vessel, whereby the carbon, manganese and silicon are oxidized and removed in the form of slag, and the product is obtained in a fluid condition.

The impurities go into the slag if solid, or out of the mouth of the vessel if gaseous.

The molten metal still contains a certain amount of oxides and gases, which are removed by adding manganese, in the form of spiegel, and in such proportion as to give the steel the proper percentage of carbon.

Bessemer Process.

The molten pig iron from the blast furnace, mixer, or cupola, is put into a large pear-shaped vessel called the *converter*, the bottom of which is double, the inner one being perforated with numerous holes to admit air to be forced in under pressure.

The converter consists of a steel shell lined with suitable fire-brick, and mounted at the middle on trunnions so it can be tilted to various angles.

The molten iron, from 5 to 15 tons at a time, is poured into the converter while the latter is lying on its side, then the air is turned into the double bottom as the converter rises to a vertical position.

The air has sufficient pressure to prevent the molten metal from entering the holes in the bottom, and it streams up through the molten iron, burning out the carbon, silicon, and manganese, accompanied by a brilliant display of sparks and a flame shooting out of the mouth of the converter. Fifteen tons of molten pig iron contain nearly three-quarters of a ton of carbon, and since this is all burned out in less than fifteen minutes, the rapid rate of combustion increases the heat of the metal very much; the air blast does not cool it, as one might suppose, and scrap has to be added, or steam, in order to keep the temperature within proper limits.

The flame, therefore, at first red, due to the manganese, becomes brighter as the carbon is attacked, until it is so white that it can scarcely be looked at with the naked eye, but finally the sudden dropping of the flame gives notice that the carbon is all burned out, and the blue tinge shows that the iron is being attacked and that it is time to shut off the blast.

The metal in the converter is then practically liquid wrought iron.

The converter is then laid on its side again, the blast shut off, and a certain amount of spiegel added so as to give the amount of carbon, manganese and silicon desired in the steel, which is then ready to be poured into the molds.

Each Bessemer plant has from two to four converters, with appliances for pouring in the molten pig iron and pouring out the molten steel. Blowing engines must also be provided, and, when necessary, cupolas for melting the pig iron.

CHAPTER V.

OPEN HEARTH PROCESS OF MAKING RAIL STEEL.

In the basic process (which is the one commonly used) the charge is placed on the bottom of specially designed furnaces, and over its surface a gas flame plays back and forth. The flame is maintained at such a high temperature that the charge is melted or kept molten, and so remains, until the proper proportion of carbon is obtained, and the steel is then tapped out into a ladle.

The furnace is rectangular in shape, and comprises a hearth which contains the charge, covered with an arched roof of bricks 9 inches to 12 inches thick, with ports or passages at each end, the air and gas for combustion entering at one end and leaving at the other; regenerative chambers at each end, connected with the ports by vertical flues leading to the chimney; and at the bottom of the flues small chambers for catching small particles of cinder or dirt.

The hearth consists usually of metal plates lined with silica bricks on top of which are placed magnesite bricks covered with crushed dolomite, some-

times mixed with a little pitch or tar. The hearth is rectangular in shape, with charging doors in front, and is provided at the back with a *tap* hole which is stopped up with refractory material. The roof and walls above the slag of the charge are built of silica bricks, and below of magnesite bricks.

The regenerators are fire-brick chambers nearly filled with bricks set on edge and arranged so as to leave a greater number of small passages, which abstract most of the heat from the outgoing waste gases, and return it later to the incoming cold gases for combustion.

Reversing valves are located where the gas and air flues meet before entering the regenerators, and about every twenty minutes while the furnace is in operation, the valves are shifted and the currents of air and gas turned in the opposite direction.

With this type of furnace a temperature of 4,000 degrees Fahrenheit can be attained.

While in the Bessemer process, pig iron only is used as the charge in the converter, in the Open Hearth process, wrought iron or steel scrap of any character, as well as pig iron, may be used, as the high temperature of the furnace will readily melt the scrap. This is the great economical feature of the Open Hearth process—as the charge may consist of, all scrap, all pig, one-half scrap and one-half pig, or any other proportion of each or both, as may appear most advantageous at each mill.

When the pig iron or scrap contains too much phosphorus, burnt lime is added, and the resulting slag will absorb the phosphorus, thus taking it out of the metal.

Each furnace has several charging doors. They were originally charged by hand, but in the modern

large furnaces, the molten pig iron, solid pig, and scrap, are all inserted in the furnace by a *charging machine.*

Furnaces used in this country for the manufacture of rail steel have a capacity of about 40 to 100 tons, although some hold as much as 250 tons; the latter are called *continuous* or *Talbot* furnaces, and only from 75 to 100 tons are tapped from the furnace at one time.

A heat usually takes from 8 to 12 hours, and a furnace will make about 12 to 20 heats per week, depending upon the size.

When completely melted the molten metal should contain about .60 per cent carbon. To determine this, a sample is taken out in a spoon and poured into a small mold, then chilled in water and broken. Examination of the fracture gives the desired information, and small quantities of ore or pig are then added, in order to bring the carbon to the right proportion.

Just before tapping a small amount of ferro-manganese is usually thrown into the furnace to effect a partial deoxidation of the bath, and assist in retaining the proper proportion of carbon.

When the bath is in the right condition, as regards both composition and temperature, it is run out of the furnace through the tapping hole, is caught in a ladle, and then poured into the molds.

The practice most generally followed is to work the carbon down below the amount desired in the steel, and then bring it up by adding some form of recarburizer, as hot iron, spiegel, coal or coke.

A few of the mills tap the furnace as soon as the carbon gets down to or slightly below the amount desired, and then bring it up to the proper proportion by adding coal or coke in the ladle.

Open Hearth Process.

The *Open Hearth* process may be either *acid* or *basic,* though the latter is in more general use.

In the *basic* process a large amount of lime is used in melting down the steel in order to remove some of the phosphorus in the charge, whereas no lime is used in the *acid* charge.

In the *acid* process the hearth is made of ordinary silica fire-brick; in the *basic* the fire-brick is of magnesia or basic material, as the ordinary fire-brick would be attacked by the lime.

In the *acid* process no phosphorus is removed, and the furnace charge must therefore be as low in that element as is desired in the finished product.

CHAPTER VI.

FROM FURNACE OR CONVERTER TO ROLLING MILL.

A *BLOW* of BESSEMER STEEL—In the Bessemer process each melt of steel made in the converter is caller a *blow,* but also called, as in Open Hearth process, a *heat.* Each blow furnishes from 5 to 15 tons of molten steel, depending upon the size of the converter, and each converter can make from 15 to 25 blows every 12 hours.

A *HEAT* OF OPEN HEARTH STEEL—In the Open Hearth process each melt of steel made in the furnace is called a *heat.* Each heat furnishes from 40 to 70 tons of molten steel, depending upon the size of the furnace, and each furnace can make one heat every 8 to 12 hours.

LADLE—Both in the converter and the furnace a considerable amount of slag or cinder is formed, which rises to the top and floats on the surface of molten steel. In order to prevent the slag from entering the molds, the molten mass is poured from the converter, or tapped from the furnace, into a ladle.

The ladle is a large pot made of iron or steel plates lined with fire-brick. It is provided with a hole in the bottom, called the *nozzle,* through which the contents are discharged into the molds. The discharge is regulated by a stopper consisting of a steel rod enclosed in special hollow fire-bricks; the brick on the lower end fits over the *nozzle* and is called the *stopper head,* the upper end is connected with a lever on the outside of the ladle. The *stopper head* is usually of graphite. Good practice tends towards holding the metal in the ladle long enough for the impurities to rise to the surface, and the time the heats are so held is an important factor of the soundness of the ingots.

TEEMING THE INGOTS—The steel casting is called an *ingot,* the molds into which the molten steel is poured are called *ingot molds,* and the process of filling the molds with the molten metal is called *teeming,* or *pouring.* The bottom-pouring style of ladle is universally employed, as by this means slag can be prevented from entering the molds, splashing of metal on the sides of the molds can be avoided, and pouring can be better regulated. Occasionally, through faulty setting, on account of some obstruction, or through burning off of the stopper-head, the stream of steel cannot be completely shut off—this is termed a *gripping* stopper, and if control is lost entirely it is called a *running* stopper.

At the commencement of teeming the stopper frequently sticks, or the metal may solidify around the nozzle, thus preventing its ready flow; in such case a *pricker* of wood or steel is forced up through the nozzle in order to start the flow. If, as sometimes happens, due to chilling, the pricker fails to open the nozzle, the hot metal must be poured over the top of the ladle, and this is called a *chilled heat.*

INGOTS—The ingot molds are usually rectangular in cross section, open at both top and bottom, and vary in size at the different mills, from 18 inches by 19 inches to 23 inches by 29 inches at the bottom, tapering to slightly smaller dimensions at the top, and are from 66 inches to 82 inches in height. Each *Bessemer blow* makes from four to ten ingots while each *Open Hearth heat* makes from 15 to 40 ingots.

Tne ingot molds are set on small cars or buggies running on a track, so they may be removed expeditiously to the *stripper.*

STRIPPER—The stripper is a machine which lifts the ingot mold off the ingot, leaving the latter standing upright on the car. The stripping should be done as soon as the outside of the ingot has solidified. The ingot is then weighed and is taken up by a traveling crane and placed in a reheating furnace called a *soaking pit.*

SOAKING PITS—These are furnaces in which the ingots are placed and allowed to remain until the temperature in all parts of the ingot has become equalized. They are then ready for the rolling mill.

The ingots must always be kept in a vertical position until they are taken out of the soaking pits, in order that none of the molten metal in the interior of the ingot may escape, (called "bled ingots") and so that the usual shrinkage cavity will be centrally located. A delay between teeming and stripping ingots, and between stripping and charging in the soaking pits, may seriously affect the soundness of the ingots. The best practice requires the hot ingots to be placed in the soaking pits as soon as possible after they are teemed, stripped and weighed.

RECARBURIZATION—This means the addition of carbon, in some form, in order to obtain the desired proportion of that element in the finished steel.

It is also used to describe the addition of other materials in order to give the steel the desired composition and to effect its deoxidation. In the latter sense it is preferable to call this *material additions*. To indicate some particular material, its name is prefixed; e. g., *Manganese addition.*

ADDITIONS—The additions are frequently made cold, generally in the ladle, and are termed *ladle additions.*

If they are in such amounts that there is danger of chilling the metal they may be preheated, or melted, or added in the furnace, in which case they are termed *furnace additions.*

In manufacture of rail steel the usual additions are silicon and aluminum, the former being added in the ladle, the latter in the ingot molds. Titanium is also used.

These additions tend to purify the metal, prevent segregation, and give quiet-setting steel. Aluminum and titanium, however, tend to increase the pipe.

PART III

ROLLING THE RAIL

INTRODUCTION.

The mechanical treatment of the rail in rolling, is of at least equal importance with the work of obtaining sound steel of the proper chemical composition.

Sound ingots, free from blow holes, pipes, segregation and impurities, are only preliminary to rolling good rails.

Wearing qualities, resistance to abrasion, great strength and toughness, are qualities that depend largely upon the rolling practice, and the fineness of grain developed thereby. The more mechanical work done on the rail, the greater will be its toughness and ductility.

The rolling-mill practice at the various steel plants varies considerably, as will be seen by an examination of the table on page 42, which shows the difference in the size of ingots used and in the number of passes used in the blooming and shaping mills. On account of this variation no one method can be described which would apply to the methods used at more than one mill. While the table gives general information concerning all the rolling mills in America, a detailed description of the rolling mill practice followed at two of the mills, with details of steel manufacturing process at one of them, is given on pages 44 and 45.

Good mill practice tends towards increasing the number of passes, decreasing the amount of reduction in cross section per pass, and perhaps getting the desired output by increased speed of the rolls; not by digging into and tearing the metal, as is

liable to be done in the cases where too few passes and heavy draft are customary.

Reducing the metal gradually by a large number of passes, tends to work and knead the metal and produce a tougher and more elastic rail. It would seem that more time might be given to the last five or six passes through the rolls, and that the finishing temperature should be as low as possible in order to get a fine-grained structure.

Some mills are installing continuous reheating furnaces to insure the rolling of blooms into finished rails at more uniform temperatures; the reheating furnace also tends to relieve internal stresses caused by blooming.

One or two mills make a careful examination of the surfaces of the cold blooms and cut out all surface imperfections before reheating and rolling into rails.

One mill has installed a milling machine which removes a thin layer of metal from the head and base of the hot rail in its passage through the rolling mill, surface seams and other imperfections being eliminated with this layer of metal.

One or two mills make a regular practice of discarding from 20 per cent to 30 per cent, thus eliminating the "A" rails, the top rail of their product being given the letter "B."

The question of heat-treating finished rails has been given consideration in recent years, but on account of the length of the rail and the unbalanced character of its section, it is a very difficult problem to solve, and a satisfactory method has not yet been developed.

CHAPTER VII.

THE ROLLING MILL.

This is a device for reducing and shaping the section of the steel ingot into the finished rail, the desired result being obtained by passing the hot metal between revolving cylinders, termed *rolls*.

A rolling mill consists of the *rolls*, set in a suitable framework to support them, called *housings*, and connected with the engine by *spindles* and *pinions*.

The rolls consist of (a) a middle portion called the *body* or *barrel*, which comes in contact with the piece being rolled; (b) the ends, which rest in the bearings, called *necks* or *journals*, which are of smaller diameter than the middle portion to permit the body of the rolls to come close together; and (c) the portion at the fillet connecting the body and the necks called the *shoulders*.

The rolls are cast to rough shape, with necessary depressions or *grooves* to give the metal the desired shape, and then turned down to exact size.

While in use the rolls are sprayed with water to prevent them from becoming overheated.

A *pass* is the opening between a pair of rolls formed by corresponding grooves, and is also the term used to describe the passing of the piece of metal between the rolls.

The housings are of cast iron or cast steel, secured to massive foundations so they will be perfectly rigid. Each housing looks like an elongated "U," the open space being large enough to hold suitable bearings or brasses in which the necks of the rolls rest, the bearings being held in place by *chucks*.

A set of rolls and the housings which hold them are called a *stand*, and two or more stands connected together constitute a *train*. The stands may

be placed one in front of the other; i. e., in *tandem.*

Mills are termed *two-high,* or *three-high,* depending upon whether there are two rolls or three rolls one above the other in the stand.

The two-high mill is generally used for plate and shape mills, the three-high for blooming mills; both kinds being, therefore, necessary in rolling rails.

The pieces of metal from which rails are rolled are too large to be manipulated at the rolls, or from one stand to another, by hand. The metal is therefore supported on a set of rollers, one on either side of a roll stand, called a *table.* The table rollers are connected with the engine, and being turned in one direction carry the piece back through the rolls through which it has just passed, or, turned in the reverse direction, carry the piece on to the next stand of rolls.

In order that the metal may receive an equal amount of work on all sides, a device called a *manipulator* is used; this has projections called *fingers* passing up between the rollers in the table, which catch the edge of the piece and turn it through 90 degrees after a certain number of passes.

With the three-high mill, the piece being rolled must be raised or lowered a distance equal to the diameter of the middle roll; two kinds of tables, operated by hydraulic power, are used for this purpose. When the whole table is raised and lowered, but always remaining horizontal, it is called a *lifting table;* when the table is pivoted so that only the end nearest the rolls is raised or lowered it is called a *tilting table.* The former is generally used for blooming mills, the latter for plate and shape mills; both types being used in the rolling of rails.

With large pieces, where marks on the surface are not objectionable, the rolls have shallow grooves cut

in their surface, called *ragging* or *cogging,* whereby a better grip of the rolls on the piece is obtainable.

The size or rating of a mill (for everything but plates) is based upon the diameter of the rolls; thus a 30-inch blooming mill, or a 16-inch bar mill, means that the rolls are of those respective diameters.

When used for rolling small pieces the mill is called a *bar* or *merchant* mill; for larger sections it is known as a *shape* mill.

The ingots are first rolled in a *blooming* mill, producing *blooms, billets,* or *slabs,* which then pass to the *shape, bar,* or *merchant* mills.

The name *bloom* is used where the cross section of the piece is greater than 36 square inches, *billets* and *slabs* when the width is not less than twice the thickness. Another distinction frequently drawn is that ordinarily a *bloom* will be rolled immediately, by the mill that made it, into the finished product, whereas a *billet* is usually a merchantable product and sold to other mills.

CHAPTER VIII.

AMERICAN RAIL MILLS—ROLLING PRACTICE.

Compiled by Robt. W. Hunt & Co., Chicago.

Name of Steel Co.	Location	Size of Ingot Molds		Kind of Steel	Number of Passes in		No. of rails made per ingot		
		Section at Bottom	Hght.		Blooming Mill	Rail Mill	100 lb. Rail	90 lb. Rail	80 lb. Rail
Algoma Steel Co.	Sault Ste Marie, Ont.	19 x23 18 x19	72 70	Bess. & O. H. (s)	16 to 19	11	4	5	6
Bethlehem Steel Co.	So. Bethlehem, Pa.	19 x23	72	O. H. (s)	13 to 15	11	6	7	8
Cambria Steel Co.	Johnstown, Pa.	20 x23 23 x29	78	O. H. (s)	13 to 15	12	6	7	8
Carnegie Steel Co.	Braddock, Pa.	23 x23	71	O. H. (s)	11	13	4	4	6

Carnegie Steel Co.	Youngstown, Pa.	19 x21	74	O. H. (s)	9	11	4	4	5
Colorado Fuel & Iron Co.	Pueblo, Col.	18 x20	67	O. H. (s)	15	10	4	4	4
Dominion Iron & Steel Co.	Sydney, N. S.	18½x21½	82	OH (s) & (d)	13 to 19	11	5	5	6
Illinois Steel Co.	Gary, Ind.	20 x24	79	O. H. (s)	9	9	6	7	8
Illinois Steel Co.	So. Chicago, Ill.	18 x19½	67	Bess. (s)	9	9	3	4	4
Lackawanna Steel Co.	Buffalo, N. Y.	19 x19	72	OH (s) & (d)	6	9	4	4	5
Maryland Steel Co.	Sparrows Pt., Md.	20 x21	68	O. H. (d)	13	11	4	5	5
Monterey Iron & Steel Co.	Monterey, Mex.	19 x22	66	OH (s) &(d)	15	10	4	4	5
National Tube Co.	Lorain, Ohio	22 x26	72	O. H. (s)	21 to 25	11	6	6	8
Pennsylvania Steel Co.	Steelton, Pa.	20 x24	74	OH (s) & (d)	19	10	4	4	6
Tenn. Coal, Iron & R. R. Co.	Ensley, Ala.	24 x24	79	OH (d) & (t)	15	9	6	8	9

NOTE—(s) means straight process; (d) means duplex process; (t) means triplex process.

CHAPTER IX.

OPERATION OF ROLLING MILL AT GARY, IND.

From the Railway Age Gazette.

The first group of rolls consists of four stands of continuous 40-inch mills arranged in tandem, requiring no manipulation from stand to stand. Sufficient distance is left between successive stands to enable a quarter turn of the ingot or bloom to be made, so that it is worked qually on all sides. The first two stands are equipped with 42-inch rolls, enabling 20-inch and 24-inch ingots to be used.

After passing these four mills the ingot is sent to a 40-inch, three-high, blooming mill, equipped with lifting tables, and is given five passes. The resulting bloom, 7½ inches by 8 inches, is sheared in two, and the crop ends or butts cut off and are taken outside the mill.

Each bloom then goes through a 28-inch roughing mill which is equipped with tilting tables. This mill has three stands of rolls, the roughing stand being three-high, the other two-high. The roughing mill gives the bloom three passes.

It then goes through a two-high forming mill for one pass.

It is then sent to the finishing mills, consisting of five stands of 28-inch mills. After the dummy pass, the bloom is transferred to the first edging, which is in this same mill, but the second stand, and turns back on an elevated table to the second edging, which is in line with the 28-inch roughing mill. It then travels by chain transfer to the lower tables, and on the leading pass goes through a stand which also is in line with the roughing mill and driven by the same motor, and continues on to the third stand of the 28-inch finishing mill, this being the eighteenth and last pass.

While the rails are getting the finishing pass they are branded.

After the finishing pass the rail travels through to the hot saws, of which there are five, thus cutting four rails to length at one operation. These four rails consist of half the ingot. The saws have 42-inch blades arranged to be raised and lowered in unison by one controller from the hot-saw operator.

After being sawed and before passing to the cooling beds they are stamped with heat number and rail letter.

As the capacity of the mill is 4,000 gross tons per 24 hours, there must be four-rail length sawed about every half-minute when working to full capacity.

CHAPTER X.

MANUFACTURE OF STEEL AND OPERATION OF ROLLING MILL AT PLANT OF ALGOMA STEEL CORPORATION, SAULT STE. MARIE.

The blast furnace metal is poured into mixers, of which there are two, one at the Bessemer plant with a capacity of 150 tons, and one at the Open Hearth plant with a capacity of 250 tons.

Rail steel is made by both Bessemer and Open Hearth straight processes, but as the demand for Bessemer rail is decreasing rapidly, the Company is now contemplating the introduction of the duplex process, which will enable them to keep their Bessemer plant in operation and reduce the time in the Open Hearth furnace.

The Open Hearth furnaces are charged with limestone, ore or roll scale, rail ends, bloom butts, and other scrap, including crop ends of all kinds, and hot metal, in the order mentioned. No scrap

outside of that made in the plant is used, as the location of the plant does not permit such to be obtained at economical prices.

At the Bessemer plant there are two five-ton converters with a capacity of 850 tons per twenty-four hours. There are also four cupolas for melting cold pig iron.

At the Open Hearth plant there are eight basic-lined, stationary furnaces; four of 40 tons capacity each, and four of 80 tons capacity each. Total capacity 25,000 tons per month.

The carbon is worked down to about .45 to .55 per cent and recarburized by adding Pocahontas coal to the ladle; if the carbon gets below .40 per cent, hot metal from the mixer is added in the furnace.

About 25 per cent of the ferro-manganese is added to the furnace just before tapping, the remainder being added to the ladle, as is also the ferro-silicon; all the ladle additions being made while the metal is pouring from the furnace. No other additions are made either in the ladle or the ingot molds.

The average time of a heat in the furnace is twelve to fourteen hours for the larger, and seven to ten hours for the smaller, furnaces.

The average time required for tapping from furnace to ladle is ten minutes, and after tapping, the metal is immediately teemed into the ingots, through a 2-inch nozzle, controlled so that the stream of molten steel is gradually decreased as top of ingot it reached.

The ingot molds are of two sizes, one 19 inches by 23 inches, the other 18 inches by 19 inches, at bottom, by 72 inches and 70 inches in height.

The average number of ingots per heat is fifteen.

The average time betwen casting and stripping is thirty-five minutes.

After stripping, the ingots are weighed and taken to the soaking pits, of which there are five, having a total capacity of 96 ingots.

The average time between stripping and charging is fifteen minutes.

The ingots are held in the soaking pits about two and one-half hours.

The ingots are bloomed in from 16 to 19 passes to a cross section of 8 inches by 8¼ inches, in a two-high, 35-inch reversing mill driven by either 4000 h. p. motor or 55-inch by 60-inch twin reversing steam engine. Average time for blooming each ingot is two minutes.

The blooms are cropped by a vertical steam shear, and cut into two parts, each part ordinarily making two rails (of the heavier sections).

The blooms are taken by a transfer crane to reheating furnaces, of which there are three, each holding 16 blooms; the blooms remain in these furnaces from 30 to 60 minutes.

The bloom then is given eight passes in a three-high, 23-inch roughing and intermediate mill, driven by a 36-inch and 65-inch by 68-inch tandem compound steam engine.

The bar is then given three passes in a three-high, 28-inch finishing stand, driven by a 40-inch by 48-inch steam engine.

The total number of passes from ingot to rail is from 28 to 30.

Average time between roughing mill and finishing mill is 2 minutes 45 seconds, and the first rail is sawed 25 seconds after.

The rails are sawed to length singly.

The cambering machine is well regulated and the rails are turned while on the hot beds, so that nearly straight rails, slightly base high, go to the straightening presses.

The stamping is done by a machine wheel, and the rail letter applied by hand.

There are two hot beds, each holding 65 rails, five cold straightening presses, and five pairs of drills; all well covered and protected from the weather.

The rails are skidded on to cars placed on a depressed track.

The mill can furnish rails up to forty feet in length, and provision is to be made for longer lengths.

CHAPTER XI.

FROM ROLLING MILL TO CARS.

Good rails cannot be made from poor ingots but poor rails can be made from good ingots; therefore, as much care should be used in the processes following the rolling as is used in the manufacture of the steel, and in the rolling of the rail.

At Gary and Birmingham several rails are cut to length at one operation by *gang* saws, but at nearly all the other mills the rails are cut to length singly.

While on their way from the hot saws to the cambering machine, the heat number, rail letter, and ingot number, where required, are stamped on the web of the rail.

The outer edges of the base of the rail cool more rapidly and become more rigid than the head. The head and base are cut to same length at the hot saws; but as the head is the hotter its shrinkage

would be greater and its cold length less than the base. This is corrected by the cambering rolls, which stretch the head to the length necessary to compensate for its greater shrinkage, and leave the rail straight after it has cooled.

The cambering machine is somewhat similar in action to a *roller* rail-curving machine; it generally consists of two horizontal rolls bearing on the web of the rail, with vertical rolls bearing on the head. The vertical rolls have a screw-motion, and by regulating the pressure imparted by the vertical rolls (which will depend upon the section of rail being rolled and the temperature at which it reaches the cambering machine), the amount of curve or *sweep* put in the hot rail is just sufficient to produce a rail that is straight, or nearly so, when cold.

The differences in form and area between head and base of rail, makes the rails tend to cool *high* or *low* unless they are cambered as above; no difficulty is encountered in having the rails cool straight, or nearly so, in *line*.

This is a very important detail of the rail manufacturing process, because the straighter the rails when they leave the cooling beds the less the work required on them at the cold-straightening presses, and consequently less danger of rupturing the metallic structure.

It is impossible to take a bend or kink out of a cold rail without straining it beyond its elastic limit.

After leaving the cambering machine the rails pass to the hot beds, and after being allowed to cool, are cold-straightened in the *gagging* presses.

After straightening, the rails are inspected, the bolt holes drilled, rails re-inspected, and then they are loaded on cars for shipment.

Rolling Mill to Cars.

At some mills the ends of the cold rails are cut perfectly square and true, and to exact lengths specified, by milling machines.

Most of the mills are now using electric magnet cranes for loading the rails on cars, and with this method the danger of damage in handling (at the mill) is eliminated.

At many of the mills the hot beds are now enclosed on all sides, thus preventing rain or snow from coming in contact with the hot rails, and also keeping off strong winds; by this means, and by careful spacing and turning of rails on the hot beds, uniform cooling is secured.

PART IV

CAUSES OF RAIL FAILURES.

INTRODUCTION.

Rail failures may be ascribed to three general causes:

1. Defects in the rails, due to imperfect manufacturing processes;
2. Defects in the track, due to inferior construction or maintenance; and
3. Defects in equipment, including improper operation thereof.

These primary causes may be aggravated by carelessness in loading or unloading rail, and by extremes of temperature, especially extreme cold weather.

Statistics show that failures in northern latitudes are much more numerous than in warmer climates, under similar service conditions and with the same kind of rail. Steel is more sensitive to shock in cold weather, and with frozen roadbed the shock is undoubtedly greater than in warm weather with elastic roadbed.

Occasionally a rail will break without any of the above-named causes being apparently responsible, but such cases are rare, and progress is being made towards development of the causes.

It is now generally admitted that wheel loads have about reached the safe limit for the present Carbon steel rail, and railroad engineers are considering what may be done to avoid dangerous wheel pressures; special attention is being given to:

(a) Changes in locomotive design,

(b) Changing design of wheel tread in order to give larger surface contact on the top of the rail,

(c) Canting the rail,

(d) Using larger rail sections,

(e) Using special alloy steels to increase the hardness and tensile strength, without at the same time decreasing the ductility.

With the large wheel loads now in use the injurious effect of inferior material in the rail is more apparent, but the results obtained from some rails appear to indicate that the attention of the manufacturer was fixed more on quantity than upon quality of the output.

It is probably impossible to produce commercially a rail from melt-made steel that will be wholly free from internal defects; but with all the flaws that have been shown to be so common, it is likely that a thousand rails give satisfactory service to every one that fails, which shows that these manufacturing defects can be tolerated if kept within proper bounds.

CHAPTER XII.

Article 3.—PIPE.

This is a defect which will occur in every cast steel ingot, unless special steps are taken to prevent it.

During the cooling and solidification of any casting the outside, or portion in contact with the walls of the mold, cools first, and the cooling proceeds gradually towards the center of the ingot.

As the metal cools it also contracts, that is, it occupies less space when solid than when liquid, so that eventually, a cone-shaped opening in the casting is left near the top of the ingot. This contraction cavity is known as a *pipe*.

The photographs on the opposite page show one-half of two ingots which have been split vertically through the center, to show the pipe that is formed in rail-steel ingots under present mill practice.

VERTICAL SECTION THROUGH THE CENTER OF TWO INGOTS, SHOWING THE PIPE.

Fig. 1.

IN THIS INGOT ALL PIPE CAN BE ELIMINATED BY A DISCARD OF ABOUT 16 PER CENT.

Fig. 2.

IN THIS INGOT A DISCARD OF OVER 50 PER CENT WILL BE REQUIRED IN ORDER TO ELIMINATE THE PIPE.

That portion of the ingot containing the pipe is objectionable in any rolled product, and particularly so in rails; therefore, especial pains is usually taken to discard it. This is not difficult to do when the pipe is confined to the upper portion of the ingot, as shown in Fig. 1.

When, however, the pipe is broken up, and continues down into the central and lower portions of the ingot, as shown in Fig. 2, an extremely dangerous condition presents itself. In such case, the usual amount of discard may not disclose the separate cavities existing below the main cavity, and rails containing these dangerous defects, if placed in service, are liable to sudden failure without previous indications thereof.

When sufficient deoxidizers are used to purify the steel, then, as must be expected, a small cavity starts to form in the top under the cap of the ingot, and its development can be retarded by early stripping of the ingot and promptly charging it into the soaking pit.

The shrinkage cavity is of greater volume and depth in long ingots than in those which are short and stubby.

Pipes always occur in the center of the ingot, and consequently appear in the center, or web, of the finished rail; except when, as heretofore pointed out, the ingots are not kept vertical.

The sides of the pipe are pressed closely together in the passage of the ingot through the rolls, and if the walls of the pipe in a broken rail be examined, they will be found to be smooth instead of granular, showing that the walls did not weld together.

Pipe may be lessened, or altogether eliminated by:

(a) Casting in wide ingots,

(b) Casting in sand molds,

(c) Slow feeding,

(d) Liquid compression,

(e) Casting with the large end of the ingot up,

(f) Use of a sinking-head, or other means of retarding the cooling of the top walls of the ingot,

(g) Combinations of the above.

Some of these methods are now being tried and give promise of good results.

Some mills, by exercising great care in deoxidizing and obtaining a quiet-setting steel, and by prompt handling of the ingot from the teeming to the soaking pit, so reduce the pipe that it is all removed in the usual discard.

Article 4.—SEGREGATION.

The elements Carbon, Sulphur and Phosphorus have different, but lower, melting points than the iron containing them; consequently those having the lowest melting point will tend to separate, and to collect in the hottest part of the ingot, that is, the top and center of the ingot, which is the last to solidify.

This concentration of these elements is called *segregation.*

In addition to segregation of elements above mentioned, there is also found in ingots cast and in rails rolled, compounds of these and other elements; e. g., iron oxide, manganese sulphide, etc. These evidently originate in the slag formed prior to teeming the ingots, and frequently act similarly to the segregating elements, and may produce lines of weakness if found in the finished rails in excessive quantities.

The top and center of the ingot will therefore contain the largest proportion of the impurities and segregated elements, and other parts of the ingot will have a deficit of these.

It is the aim of the mill to have the molten steel leave the converter or furnace with as small a proportion of impurities as is commercially practicable, and to have the elements distributed evenly throughout the ingot.

The term *positive segregation* is applied to cases where too much of an element is found in one portion of the steel, and *negative segregation* in cases where less than the prescribed amount is found.

Segregation may be lessened by:

(a) Allowing more time in the furnace for the material to become thoroughly mixed and homogeneous, and then holding in the ladle long enough to allow the impurities to rise to the top of the molten metal;

(b) Adding Silicon, or Titanium, to the molten steel in the ladle and holding as in (a), or by adding Aluminum in the ingot mold, or by both additions;

(c) Casting in small ingots instead of large, and hastening the solidfication, not only by this means but also by

(d) Casting at a low temperature,

(e) Casting in thick-walled molds, and

(f) Casting slowly.

By use of a sinking-head the segregation all forms in the top part of the ingot and is eliminated, with the pipe, in the usual discard.

Nearly all the mills are using methods (a) and (b), as well as some of the other methods, with good results.

While segregation is greatly reduced by use of the deoxidizers mentioned in (b), pipe is usually increased thereby, except in the case of Silicon.

Article 5.—BLOWHOLES.

Blowholes generally form in the upper half of the ingot which is permeated by honeycombs or dispersed cavities, due to liberation of imprisoned gases. These gases are absorbed or occluded in the molten steel, but are wholly or partially evolved and collect into bubbles when the metal begins to solidify, and any which cannot escape are mechanically held in little pockets called blowholes or gas holes.

Small, deep-seated blowholes, i. e., those a conerable distance from the sides of the ingot, are not very objectionable, and are ordinarily welded up in rolling. The larger blowholes may be entirely prevented by a thorough deoxidation of the steel by additions of Silicon, Titanium or Aluminum. These metals not only prevent blowholes, but also prevent the evolution of gas.

The complete elimination of iron oxide is the best preventive of blowholes.

If steel is so thoroughly deoxidized that no blowholes form, the size of the pipe will be correspondingly increased, and conversely, if a sufficient number of blowholes be permitted to form, the pipe may be almost entirely avoided.

For this reason some manufacturers desire a small number of blowholes to form, so that a deep pipe will not necessitate a heavy discard from the ingot; but this practice is dangerous because of the difficulty in so controlling their position that they will be deep-seated instead of near the skin of the ingot, and because the blowholes are not always welded up in the rolling.

If an ingot with blowholes near the surface of its sides, be permitted to remain longer than usual in the soaking pit, the oxidizing action will remove

portions of the metal, and with heavy reductions in the blooming mill, surface seams will undoubtedly be present in the finished rail.

Article 6.—SLAG INCLUSIONS.

The presence of slag in finished steel is much more universal than is usually supposed.

These slag inclusions vary all the way from minute particles scarcely visible under the microscope, to pieces easily discernible to the naked eye.

Slag inclusions tend to cause steel to be brittle and unreliable, and to create microscopic fissures and flaws which continuously develop under service, and often cause sudden failure.

One of the most objectionable impurities is manganese sulphide. When the spiegel (ferro-manganese) is added to the molten metal, part of the manganese is liable to combine with the sulphur of the steel, and given time enough, will with all the other impurities, float up into the slag on the top of the molten steel.

Good practice requires an interval of time between the additions of the spiegel and the teeming of the ingots. Some railroads classify as *piped rails* all fractures which show a seam. These may not always be due to pipe, but may be slag or gas seams; however, the effect is the same.

Article 7.—DISCARD.

Each heat of steel differs from every other heat, and the same is true of every ingot in the same heat. This dissimilarity is due to differences in temperature, to the reactions and chemical composition resulting therefrom, to varying condition of molds, to time taken between teeming of ingots and

placing them in the soaking pits, and to conditions of reheating and time when they are given the first pass in the blooming mill. All these have an influence on the location and amount of unsound metal in the ingot, and which it is the object of the discard to prevent getting into the rails.

The two greatest defects, pipe and segregation, are usually found in the upper thirty per cent of the ingot. Until some remedy has been adopted to prevent or minimize their occurrence, it is often necessary to specify that a certain percentage from the top of the ingot shall be cut off and discarded, not used in the finished product. By this means it is hoped that nearly all of the imperfect metal will be eliminated.

However, the general tendency now is, to require the blooms to be sheared until sound metal appears. This leaves a great deal to the judgment of the shear operator, and does not always produce the desired results.

The only way to ascertain definitely whether all imperfect metal has been discarded, is to test a portion of the top rail of every ingot. This can be done by a chemical survey, or by a nick-and-break test and examination of the fractured surfaces.

Defective spots in the ingot, due to slag, blowholes, piping and segregation, will not be removed in rolling but must be eliminated as far as possible in the discard.

In order to get definite knowledge of the service given by rails from different parts of the ingot, specifications now require that each rail shall be stamped with a letter indicating its position in the ingot; the top rail being lettered "A," the next "B,"

the next "C," and so on. These letters can be found on the rails in the tracks, and are shown on the rail failure report.

While the practice of lettering the rails is comparatively recent, statistics so far obtained, indicate, as was expected, that the "A" rails have a larger percentage of impurities and much greater segregation than the "B" or lower rails, that they wear out faster, develop more surface defects, and must be removed from service much sooner than the other rails.

One or two mills discard nearly 30 per cent from every ingot, thus entirely eliminating the "A" rails, the top rail of their product being given the letter "B."

Article 8.—ROLLING-MILL SEAMS AND LAPS.

In the passage of the ingot through the rolls of the blooming mill, the squeezing between the rolls tends to crack and tear the sides of the ingot, especially during the first few passes, and also tends to open up the surface blowholes which may exist near the sides of the ingot.

This tendency is greater in some mills than in others, depending upon the amount the ingot is reduced in thickness at each pass (called *reduction* or *draft*), and upon the speed of the rolls.

The cracks thus developed in the skin of the ingot are closed up in the later passes, but do not always weld together.

These defects thus developed may be minimized by reducing the draft in the earlier passes, or by reducing the speed of the rolls.

Rolling defects may also be caused by the effect of red-shortness which slag enclosures produce.

Surface seams may also be caused by the small holes or pits which occur on the outer surface of every ingot, and which are elongated into seams in passing through the rolling mill.

Rolling mill laps or folds have been caused by too deep cogging of the rolls, or by a break in the roll, or by lack of proper adjustment of the rolls; and by failure of the mill to catch the defect in time to prevent some of the rails being loaded and shipped.

Seams and laps may be as harmful in their effects as segregation and slag inclusions.

An examination of the Table on page 42 will show the variation in rolling mill practice. In some mills the draft is extremely light in the first few passes, while in other mills the draft is at first heavy but the speed extremely slow: in the former it is the purpose to weld up the skin of the ingot so as to prevent the development of the defects above mentioned; while in the latter the idea is to elongate the metal of the ingot in the manner done in wire drawing.

The passage through the rolls continuously parallel with one axis of the ingot and bloom, tends to elongate the impurities and segregated materials, the blowholes, the surface cracks and pits, in one direction; so that notwithstanding the original crystalline formation of the steel, the finished rail has a structure somewhat similar to a stick of wood, and which is stronger with than across the grain. This condition is especially noticeable in the base of the rail, where the ductility in the direction of the length of the rail is much greater than at right angles thereto, or across the rail.

Article 9.—CAMBERING, COOLING AND COLD-STRAIGHTENING.

All of the care used in the various manufacturing steps up to this stage may be wasted, unless the work of cambering, cooling, and cold-straightening be properly performed.

The cambering machine, by which the hot rails are given the curvature necessary to compensate for the unequal temperature of head and base, deserves the most careful attention, otherwise the rails will be badly out of surface when cold.

The rails on the cooling beds must be carefully protected against rain or snow, sudden changes of temperature, or other unequal cooling conditions.

With all the precautions that may be taken, there is a certain amount of cold-straightening to be done on nearly every rail; but, given a well-designed rail section, the rail-maker can by exercise of proper care in manufacture and cambering, greatly reduce the amount of gagging.

It would seem that the present methods of straightening should be replaced by a method which distributes the compressions of either the head or base, or lengthens either one uniformly per inch of rail.

Acting on the suggestion of Capt. Robt. W. Hunt, a number of railroads have this year agreed to accept from the manufacturers, for experimental purposes, a small amount of rail which has been carefully cambered but not straightened, provided they contain no short bends or kinks, and that the middle ordinate of total curvature of rail when leaving the hot beds is not greater than one inch in any direction. It is hoped that this will in time lead to elimination of cold-straightening in No. 1 rails.

Causes of Rail Failures—Defects in Manufacture.

It is conceded that the strain and torture that rails have to endure in cold-straightening is a very objectionable part of the whole manufacturing and finishing process.

It is impossible to take a bend or a kink out of a rail without straining it beyond its sectional elastic limit, and setting up internal stresses which work at cross purposes with the normally cold tension of the steel. To what extent these may be harmful to the rail after it is put into service cannot be definitely determined, but it is only reasonable to infer that they have some effect.

They undoubtedly are, in many cases, the cause of external and internal fissures or breaks in the continuity of the rail structure, after the rail is placed in service develop into split heads, split webs, and broken bases, and which have been proved to be the source, in several cases, of the dangerous failures known as *transverse fissures* hereafter discussed in Chapter 19.

CAUSES OF RAIL FAILURES.

CHAPTER XIII.

DEFECTS IN EQUIPMENT AND OPERATION.

INTRODUCTION.

The service for which a rail is designed does not require it to be able to withstand indefinitely, the repeated powerful blows delivered by improperly counterbalanced locomotives, or broken and flat wheels, nor the bad effects of slipping drivers, excessive speeds, etc.

There is little excuse for operating with defective equipment, and it must be avoided wherever possible, but even with the best supervision, flat wheels or unbalanced locomotives will be found in service occasionally.

Unnecessary punishment of the rail should be reduced as far as possible, and the Mechanical Departments of the various railroad companies are continually directing their efforts towards improving the design and the maintenance of locomotives.

Locomotives now have more driving wheels than formerly, to sub-divide and distribute the load. The large freight locomotives have four and five pairs of drivers; and instead of the *Atlantic* and *American* types, the *Pacific* type of locomotive with three pairs of drivers is generally used on heavy fast passenger trains.

When a railroad has in service, rail that is obviously too light for the character of machinery operated, that rail is subjected to unreasonable stresses, and due consideration should be given to that fact in investigating cases of rail failure.

Article 10.—INCORRECT COUNTERBALANCE.

There is no lack of evidence to prove that the blows produced by improperly balanced wheels are

frequent causes of rail failures. While locomotives that may be correctly balanced for a certain speed should not be operated at much higher speeds, it is not uncommon to find them being run at speeds 30 per cent greater than that for which they were designed, and this has been permitted even in extremely cold weather.

The computations of the centrifugal and reciprocating forces are usually based on a speed in miles per hour equal to the diameter of the driving wheel in inches, which may be considered as a maximum for good practice.

The railroads are devoting a great deal of attention to reducing the weight of reciprocating parts, by use of special heat-treated carbon and alloy steel, aluminum, etc.; thus making it possible to construct very light parts, the expense being more than justified by saving in repairs to equipment and track, and by increase in tractive power of locomotive.

It has been found that by this method the weight of the reciprocating parts can be reduced to nearly 1/240 of the total weight of the locomotive in working order, instead of the usual average of 1/160.

With incorrect counterbalance, due either to poor design or to excessive speed, there is a tremendous blow delivered to the rail at every revolution of the driving wheel; these blows, however, do not as a rule leave a mark on the rail. When apparently sound rails break on well maintained track, or in cases where a number of rails are found broken or damaged on one side of the track and at regular intervals which are multiples of the circumference of the wheels, defective equipment may be suspected as the cause.

Causes of Rail Failures—Defects in Equipment and Operation

Article 11.—EXCESSIVE SPEED.

The competition among the railroads for traffic, led them gradually into offers of quicker and faster service, until a point was reached a few years ago where excessively high speeds for both passenger and freight trains was the general practice.

In some cases where track and rolling stock could not be maintained at a high standard, these fast schedules had reached the limit of safe operation. The traveler, the shipper, and the railroads were equally to blame for this condition. In recent years the tendency has been to reduce schedule speeds and hold them within reasonable limits.

On some railroads the schedule speed of the train may not be exceeded, and if a train is delayed no attempt is made to run at high speeds in order to bring the train into its terminal *on time.* The management and the trainmen do not always co-operate on this feature, and on a few railroads automatic registering speed recorders are placed in the trains, which are carefully checked at the end of a run, and in cases where the permissible speed has been exceeded a penalty is inflicted.

As indicated in the preceding article, the principal trouble caused by excessive speed is that due to counterbalancing, but high speeds accentuate any slight defects in equipment or track, and may lead to failures that would never occur when the locomotive is run at speeds no greater than the maximum for which it was designed, and which the track can safely carry.

Article 12—BROKEN AND FLAT WHEELS.

These generally leave a mark on the rail, if not at the point where the failure occurred, then up or down the track.

Causes of Rail Failures—Defects in Equipment and Operation.

Great damage must undoubtedly be done to rails by repeated hammering from flat spots on wheels.

Good railroad practice demands that new wheels shall be circular, shall be set concentrically on the axle, and that the size of the flat spot which is allowed by the interchange rules shall be strictly limited.

Article 13.—SLIPPING AND SLIDING WHEELS.

These cause *burnt* rails, that is, the metal directly in contact with the wheels becomes suddenly heated to a high temperature, and cools quickly, with the result that a hard spot forms in the metal which may develop into complete failure of the rail. Slipping of drivers may be caused, either by the enginemen, giving too much steam causing drivers to spin, or by an improper application of the air brakes locking the driving wheels or other wheels while the train is in motion, causing them to slide along the surface of the rail. The latter does double damage in that it also causes flat wheels.

With the long passenger and freight trains now in use all air equipment must be in first-class shape, or no matter how well it is handled by the enginemen, the brakes on one or more cars may fail to release, especially in cold weather.

Article 14.—WORN TIRES.

This condition causes eccentric loading, and overloads the rail at the edges of the head. It is generally admitted that wheel loads have about reached the safe limit for the present carbon steel rail, and close attention is being given to methods for avoiding increase in such pressures.

Realizing therefore that present loads on rails should not be greatly increased, especial care should

be taken to see that the tires of locomotive drivers are kept in first-class condition, and that the maximum limit of wear prescribed by the Master Mechanics' Association is not exceeded.

Rails damaged by worn tires are difficult to identify; a wheel with a false flange may be suspected as causing the trouble when the outer corner of the head of the rail shows unusual marks.

CHAPTER XIV.

DEFECTS IN TRACK.

Good railroad track involves a properly drained sub-grade, ballast, ties and rail fastenings, joint bars and other joint material, and the proper maintenance of these, as well as rails.

It would be manifestly unfair to blame the rail for failures which may be clearly due to defective support or fastenings.

When rail is submitted to an abnormal and unfair usage, it may break, and the fracture will occur, of course, along the line of least resistance; that is, to say, if there is a defect of any kind in the rail, it would be developed by defective track (and also by defective equipment) when it might not be developed under usual service stresses.

Many failed rails show no apparent interior defect, and manufacturers argue from this that the only remedy is to use heavier sections.

It is entirely probable that a great deal of rail is subjected to unreasonable treatment. There is likewise no doubt that it is entirely reasonable to require manufacturers to remedy defective practices in the mill, and to use such attention and care in the production of rail as the service to which it is put, and the safety of the traveller, demands.

Causes of Rail Failures—Defects in Track.

The following track defects may hasten the wear, or even the breakage of unsound rails, and some of them may even cause the failure of sound rails;

Low joints,
Loose or improperly bolted joint bars,
Unequal bearing produced by frozen roadbed, or poor shimming,
Unequal freezing of roadbed—thawing on south side of single track and on outside of double track,
Inferior subgrade,
Improper elevation and improper gauge on curves,
Wide gauge,
Defective tie plates or improper bearing thereon,
Unequal tie spacing,
Insufficient drainage of roadbed,
Blows from spike maul on rail,
Injuries by trackshifting machines, etc.,
Injuries in unloading and handling,
Reversing curvature, or strains, in relaying rail.

The great enemy of the trackman is water—if more study had been given to the problem of keeping water out of the subgrade fewer rail failures would have characterized the past.

The subgrade is the foundation, and no amount of money spent on rails, ties, joint bars and ballast will give successful results on an inferior subgrade.

Careful records on a certain operating district show that on one portion of the district where the subgrade is sandy, porous and well drained, the rail failures were but two-fifths of the number occurring on another portion of the district where the subgrade is a kind of clay that holds water.

Causes of Rail Failures—Defects in Track.

It is only infrequently that one reason tells the whole story. The blanks provided for reporting failures aim to get as much information as possible concerning the conditions surrounding the failure, and the blanks should be carefully studied, carefully filled out, and the diagrams carefully marked.

PART V

KINDS OF RAIL FAILURES.

INTRODUCTION.

The logical classification of rail failures seems to be one that places them under headings that are descriptive of the manner in which the failure generally develops or occurs in service. They may therefore be divided into three general classes:

1. Head failures.
2. Base failures.
3. Broken rails.

As a general rule a failure in any one of the first two classes will, sooner or later, if the rail be allowed to remain in service, lead to a failure in Class 3, and care should be taken in reporting failures in Class 3, to be certain that a failure in Class 1 or 2 did not first occur. The proportion of failures in Class 3 which were not preceded by a failure in one of the other classes is small.

Pure web failures are of infrequent occurrence, but do occur occasionally.

Especial care should be taken to distinguish between failures occurring at the joints, from those occurring in portion of the rail outside the joint bars. If after a few years service a rail fails at the joint while the balance of the rail is in good condition, it may be assumed that the failure is not primarily due to defects in the rail itself. Such failures must be covered by the usual reports, but the reports should show clearly, as provided, that the failures occurred at the joint.

Similarly, in reporting failures of rails on curves, care must be taken to show if the head of the rail has been abraded to an appreciable extent. Manu-

facturers claim that as soon as a rail has received any appreciable amount of wear, the surface metal is strained, while the metal beneath is undisturbed.

It is difficult to make a distinct classification of some failures and assign true cause or origin.

In fractures of granular structures, the point of origin of the fracture is usually easily detected by a well-defined nucelus, from which a fan-like or radiant structure diverges. With this in mind, a careful examination of the fractured surfaces of a broken rail will enable the trackman to show in his report whether the failure originated in head or base.

It is no doubt generally understood, that the term *rail failure* is not limited to those rails in which a partial break, or a break clear across the section, has occurred. Any condition of the rail, which requires its removal from service before the end of its usual life in such service, and under the local conditions, should be reported as a rail failure.

CHAPTER XV.

Article 15.—CRUSHED HEAD

In this type of failure the head flattens and broadens out, begins to sag down on one or perhaps both sides, and if allowed to remain in service the head finally splits and drops down.

This type first shows itself to the trackman by the development of a dark streak along the top of the head, indicating that a portion of the metal is depressed and is not receiving the usual brightening from the wheels. It usually develops very slowly, and should be readily detected in its earlier stages.

Crushed head failures may be caused by unsound and segregated metal, blowholes or gas seams; and often, flat wheels, or slipping driving wheels, may

contribute to these failures. With segregated metal, the crack develops in the interior of the head, where the metal is less ductile than on the surface and ruptures under the wheel loads. Slag inclusions or other impurities often form the nucleus for a split in the head.

Manufacturers claim that intense localized wheel pressure will sometimes cause such failures even in a perfectly sound rail.

When this type of failure occurs at the rail joint, the report should so indicate, as the failure may not be due to defective rail but to defective joint. Even with perfect rails, perfect joint bars, and perfect support, depressions may be worn near the end of the rail. This is due entirely to the fact that at a joint there is a tendency for the wheels to jump from one rail to the other, thus battering the rail as well as tending to cause loose joint bars, bolts, and ties.

Article 16.—SPLIT HEAD.

It is sometimes difficult to distinguish clearly between split heads and crushed heads; with true split head failures the crushing and flattening of the head does not usually appear, but a piece of the head from a few inches to a few feet in length splits off and drops down.

This type of failure is confined, almost entirely, to metal showing considerable segregation and attended more or less with laminations and slag seams.

Under certain conditions of track the action of the wheels tends to press the metal in the head of the rail outwards. The metal in the outer surface of the rail is usually ductile enough to stand this action without cracking, but if the interior metal is unsound a crack will be started, which gradually develops until it results in a split head.

Split heads have also been caused by a blow from the sharp edge of a defective wheel, which may cut the surface metal, and the final fracture not occur until later.

It is claimed that the present wheel-coning loads the rail eccentrically, and by giving insufficient contact for present wheel loads, tends to split the head and web.

Article 17.—FLOW OF METAL.

In this type of failure the metal on the top of the head flows out to the sides and forms an overhanging lip, but without any indication of the breaking down of the head structure.

This type cannot be classed as a dangerous failure in itself, but in some forms it may offer a starting point for splits or breaks.

It may appear in several forms, from small spots to large ones covering the greater portion of the length of the rail.

In some cases the metal sloughs off in several spots, causing what are sometimes called *roaring* rails, but may be properly defined as *flowed in spots.*

Flowed in spots may be caused by slipping drivers and sliding wheels, which produce a thin sheet of brittle steel at the spot where the friction occurred, and this soon breaks away from the metal beneath.

Flow of Metal may be caused by blowholes, gas seams, or other unsoundness near the surface or corners of the head. Improper heat treatment, such as will cause coarse grain, is another cause.

Shelly corners produce a condition somewhat similar to flow of metal, but these are evidently due to unsound structure.

Kinds of Rail Failures.

Flowage at the ends of rails may be due to defective joints or to inferior joint maintenance.

Stock rails at switches afford examples of the effect of natural service conditions in regard to this type of failure, where the false flange of the wheels rides on the top of the head of the rail.

Rails which show even flowage for their entire length, such as the inside rail on curves, should not, except in special cases, be classed as failed rails, as this is a form of abrasion which cannot well be avoided where all kinds of traffic are operated over the track.

Article 18.—ABRASION.

Under certain conditions of curvature and speed variation for different kinds of traffic, the head of the rail is abraded more or less rapidly, by the wheel tread in the case of the low rail, and the wheel flange in the case of the high rail.

This condition, while not classed as failure of the rail, reduces the life of the rail so materially that experiments are being carried on by the railroads with a view of overcoming the trouble.

These experiments indicate that rails of special alloy steel, or of special section, may overcome the difficulty to a certain extent, but it has not yet been determined which will prove most economical.

During the past there has been a tendency on the part of a great many railroads towards too great a widening of the gage on curves; this leads to excessive abrasion of the rail and lashing of the locomotive, especially at high speed. A great many of the leading railroads are now maintaining standard gage on curves of to 7 to 9 degrees with very satisfactory results.

CHAPTER XVI.

WEB FAILURES AND PIPED RAILS.

Article 19.—SPLIT WEB.

Failures of this type are not numerous. Ordinarily the web splits horizontally, usually at the end of the rail through the bolt holes. They may be caused by loose bolts, or by imperfect alignment of bolt holes in drilling at the mill. These end failures may also be caused by careless handling in loading or unloading in cases where rail is shipped by boat.

Web failures also occur at intermediate points of the rail; this type may be caused by rolling seams or laps, chilling by water in the course of rolling, initial stresses in cooling and excessive alternating bending either at the straightening press or in service, and some have even been causd by blows of the spike maul.

Article 20.—PIPED RAILS.

As a rule these defective rails fail completely and suddenly, without previous warning, and are therefore especially dangerous. While they are properly classed as broken rails (discussed in the following chapter), the cause of failure is due to defect in the web, and they are therefore placed in this chapter.

Piped rails are those in which the sides of the original shrinkage cavity (called the pipe) in the ingots, are found closely pressed together in the rail, but not welded together. The pipe is very distinct, and as it occurs in the center of the ingot, so we should expect to find it in the center of the web of the finished rail, and not in either the head or base. With some sections of rail, which have a preponderance of metal in the head, the pipe may extend up into the head.

If an ingot be laid on its side after casting, and allowed to cool in that position, the pipe will be near the upper surface, and may then appear in portions of the rail other than the web.

In some few cases a split head has been found running into a pipe in the web, but these cases are rare.

If split head fractures can be examined while new, the condition of the fractured surfaces will indicate if a pipe be present, as in that case the walls of the fracture will be smooth. This can also be detected in nearly all cases of old breaks.

Piped rails are caused by the failure of the mill to crop the blooms down to sound steel, thus insuring the complete elimination of the cavity existing in the ingot.

CHAPTER XVII.

BASE FAILURES.

The well known crescent or half-moon failures usually start near the center of base of rail and continue along it, sometimes a fraction of an inch, some times as much as four or five feet, and then break out to the edge of the base in a crescent-shaped curve. Sometimes one side only of the base breaks, and rails have been known to do service for some time in this condition; generally, however, the rail breaks through the other side of the base, the web, and the head, immediately after the first break occurs.

It is claimed that this type of failure is, in most cases, due to seams in the base of the rail. These seams may occur at any point across the full width of the base, but seams near the center of the base are more dangerous than those near the edge. The

seams may vary in depth from 1/32 to 1/8 inch, and extend along the base of the rail from a fraction of an inch to several feet.

In a fresh break it is generally possible to distinguish the seam at which the fracture started, as a smooth face showing a bluish surface, or corroded and rusty if the seam has been open.

These seams are usually caused by cracks or blowholes formed or opened in the early passes in rolling the ingot, especially on the two sides which are not in contact with the rolls; these are elongated in subsequent passes in the rolling mill. They may be found all over the rail, and are frequently very minute.

In all cases of broken rails the base should be carefully examined for signs of the crescent-shaped breaks, and for seams that caused them, in order to ascertain if the ultimate failure of the rail was not preceded by the failure of the base. One or two blows of a hammer will break out a crescent where the rail has base seams; without seams present the flange should bend but not split.

These failures are aggravated by cold weather, frozen roadbed with unequal bearing, poor shimming, and other defects in maintenance; but even under these conditions, failure would not ordinarily occur without the presence of seams.

Distinction should be made between the seams referred to above and those produced in the process of rolling all rails, which, as shown on page 63, tends by elongating the impurities, to give the whole rail a fibrous or seamy structure. Such seams are very minute, but are easily made apparent by polishing and etching the bottom of the rail, when the seams appear as black lines on the surface. The base of rails, where such seams are present, has less

transverse than longitudinal ductility, and with defects in track, may lead to broken bases that would not break where track conditions are good.

Broken base failures were frequent in rails with thin bases, and the A. R. A. sections were partly designed to overcome this trouble.

CHAPTER XVIII.

BROKEN RAILS.

Rail breakages are of two distinct classes, consisting of those of rails which are sound when put in track, and those of rails which have inherent defects.

The latter are more dangerous than the former, because in a sound rail the break is pretty sure to be a clean one, and the rail will ordinarily be held securely in place by the track fastenings until found and removed by the section forces; whereas, a defective rail will frequently shatter into several pieces, giving rise to serious danger of accident.

For the breakages of defective rails the rail makers must be held chiefly responsible—the remedy is better methods of manufacture.

For the breakages of sound rails by defective equipment or defective maintenance the railroads must and do accept full responsibility—the remedy is proper maintenance, and constant vigilance to remove defective equipment from service, and to properly regulate the speed of trains, especially in cold weather.

All rails which break in two or more pieces are placed in this class. However, as has been stated, there may have first been a failure in head, web, or base, which was the primary cause of total failure of the rail. Therefore, careful examination of all the fractured surfaces should be made, both for the pur-

pose of ascertaining if partial failure of portions of the rail probably occurred before total failure took place, as well as to see if the total failure apparently took place all at once, and whether or not any internal defects were present.

Broken rails are generally accompanied by brittleness and segregation; the former may be caused by too large a quantity of the hardening elements, or by improper heat treatment during manufacture.

The break may be square or angular and may be caused

1. By partial failure first occurring in head, web, or base, followed by total failure.
2. By pipes, seams, segregation or other internal defects.
3. By defective equipment or improper operation thereof.
4. By inferior maintenance.
5. By cold weather and frozen roadbed.
6. By careless handling.
7. By transverse fissures.

The first four items have been discussed in previous chapters.

5. The difference between the number of failures during warm weather, compared with the number of failures in cold weather is very marked.

Statistics of some railroads show that under similar conditions the failures in severe cold weather will run from three to five times as many as in warm weather, for the same weight and section of rail.

6. Under failures due to rough handling the initial fracture may occur at the mill at straightening presses or in loading into high side cars and letting fall upon other rails five feet or more below, or in letting the rails fall in unloading six or seven feet upon the ground.

A fracture of this type is characteristic; it begins generally across the base and extends a short distance up into the web, then it works along the web, sometimes for a distance of several feet, with the face of the fracture in a plane at right angles to a vertical line down through the rail, and finally breaks up through the head.

Some approved device should be used for unloading rails from box cars or gondolas, and in unloading from flat cars both ends should be dropped at once, and dropping on hard or uneven ground avoided.

Nearly all the rail mills have installed electric magnet cranes, and have thus eliminated practically all failures due to careless loading at the mill.

7. Failures caused by transverse fissures are discussed in the following chapter.

CHAPTER XIX.

TRANSVERSE FISSURES.

This is a type of failure which has received a great deal of attention in the last four or five years, particular attention having been drawn to it on account of several disastrous train wrecks caused by broken rails which were found to contain transverse fissures.

Few fissures have been found in rails rolled prior to 1909.

The name *transverse fissure* is given to a fractured rail section that shows smooth, dark or silvery spots on the fractured surface, while the rest of the metal shows the usual crystalline structure.

The transverse fissure is found on the fractured surface, usually without any connection with the outside skin of the rail, indicating that it is an *internal* fissure.

If moisture gets into the break before total failure of the rail, or in some cases of oxidation during manufacture, these spots are found darkened, but in many cases they are found to be bright and silvery.

Photographs are shown of several different fissures which have been found in rails that failed in service, and from which the trackman can get a good idea of the form in which these failures usually appear.

Very few fissures have been found in the base of the rail, most of them occurring in the head, as indicated by the photographs.

In the great majority of cases the plane of the fissure is at right angles to the length of the rail, but a few cases have been found in which the upper part of the fissure bends backwards and runs parallel with the length of the rail and about half an inch below the top of the head.

On account of the fissure being internal, and that as soon as it works out nearly to the outer surface of the rail, failure occurs, it is impossible for the trackman to foresee the failure, and remove the rail before it breaks.

Failures of this character are therefore the most dangerous type of failure with which the trackman has to contend.

Fortunately they are of rare occurrence, and some railroads claim that notwithstanding careful watch no failures of this type have ever been found on their lines.

Trackmen should keep a close watch for the appearance of fissures on the fractured surfaces of any rail that breaks; when any are found draw special attention thereto on their rail failure reports, and be especially careful to see that all parts of the rail in which they appear are preserved until instructions as to their disposition have been received.

Fig. 3.

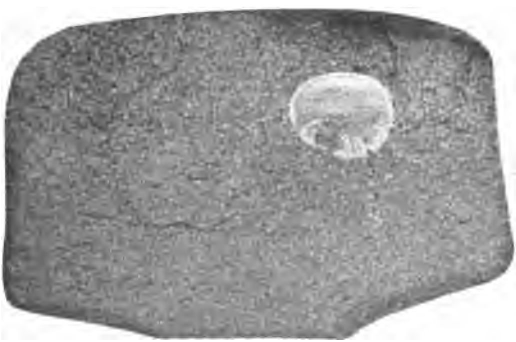

Fig. 4.

Kinds of Rail Failures.

While the United States Government Bureau, the rail manufacturers, and the railroads, have all been carrying on careful investigations, they have not yet agreed upon a theory as to the cause of transverse fissures; all, however, are agreed upon two points:

1. That the fissure starts from a point in the interior of the rail where the continuity of the structure has been broken, and

2. The fissure keeps spreading from this break, under repeated alternations of stress, until failure finally results.

The manufacturers claim
that the primary break has been caused either by overloading in service, or by the repeated alternating bending stresses produced by hundreds of passing wheels; while

The railroads claim
that the primary break has been caused by defective manufacturing processes.

The following theories of the primary cause of transverse fissures have been advanced:

(a) Fissures start from the breaking of an overstrained fibre, caused by a combination of internal strains due to cooling and the strains produced by heavy wheel loads;

(b) Fissures are caused by unequal cooling strains requiring subsequent excessive gagging to straighten the rail, especially near its ends;

(c) Fissures are caused by rolling practices which give incomplete transformations in the metal;

(d) Fissures are caused by finishing high carbon rails at too low a temperature;

(e) Fissures start from some internal defect, such as slag inclusion or a segregation spot;

(f) Fissures start from minute cracks which do not weld up in the head during rolling, but do weld up in the base;

(g) Fissures are the direct result of overloading, combined with alternate repeated bending stresses and intense wheel contact stresses;

(h) Fissures are caused by alternate repeated bending stresses of ordinary wheel loads.

Kinds of Rail Failures.

Fig. 5.

Fig. 6.

Kinds of Rail Failures.

Experiments show that metals subjected to rapidly alternating stresses, will ultimately break under a load within the elastic limit, and that the relation of elastic limit to ultimate strength is materially affected by cold rolling.

After the primary break of an internal fibre has occurred, it is admitted by all that the repeated alternating bending stresses produced by passing wheels, will develop the fissure until total failure of the rail takes place; any unusually severe strain, such as in the gagging press or caused by defective counterbalance, etc., will much hasten the development.

To illustrate the difficulty of having any of the foregoing theories accepted unanimously the following points may be noted:

1. Dr. Dudley (N. Y. C. & H. R. R. R.) finds gag marks in the vicinity of all his fissures, 92 per cent of the fissures being within 3½ feet of ends of rail.

2. Numerous fissures have been found only two inches apart, and as many as twelve have been found in one 33-foot rail, which makes it difficult to believe that they could all have been caused by gagging.

3. Mr. Jas. E. Howard (Interstate Commerce Commission) states that all the fissures he has seen have been located in the gage side of the head of the rail, whereas Dr. Dudley finds 13 per cent of all the fissures found on his lines were in the outer half of the rail head; Dr. Dudley further states that the reason these fissures usually develop on the gage side of the head is, with the present coning of wheel treads of 1 in 38 more of the load comes on that side of the head, whereas with the former coning of 1 in 20 more of the load came over the center of the head.

Fig. 7.

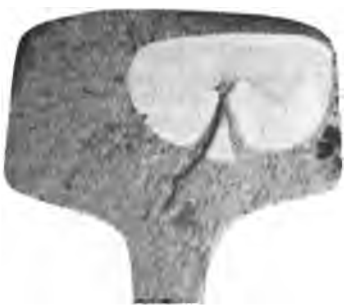

Fig. 8.

4. Mr. A. W. Thompson (B. & O. R. R.) says, if bad straightening practice is alone to blame why are not more fissures found in Bessemer rails, and why were there but rare instances of fissures in any rail prior to 1909?

5. Mr. Howard says, again, that fissures have never been found in structural steel, nor in rails that have never been in service, whereas Dr. J. S. Unger (Carnegie Steel Co.) has produced in the laboratory true transverse fissures in structural and medium carbon, as well as in high carbon steel, also in new rails that have never been in service.

6. No method has yet been discovered, whereby an examination of the interior of the section can be made prior to the development of the fissure in the laboratory, to see if the structure was sound before the experiment was started. The laboratory experiments show that the fissure can be produced at any desired point in head or base of rail.

7. As proof of the cause being in the manufacturing process, it has been found, that whereas the rails from a certain heat will under certain conditions develop transverse fissures, adjoining rails of the same section and under exactly similar conditions show no signs of transverse fissures. Mr. Robert Job (L. V. R. R.) removed rails from track upon both sides of and adjoining various failed rails of same section found to contain transverse fissures; the rails thus removed were subjected to the drop test without finding a single indication of transverse fissures. He claims that this proves that neither track nor traffic conditions were the primary cause of the fissure, and that consequently the rails that failed in service, must have contained manufacturing defects which so weakened their power of resistance, that they were overloaded by ordinary weights and stresses which exerted no injurious effect upon rails in which the steel was properly made and sound.

PART VI

SPECIFICATIONS.

INTRODUCTION.

Part VI contains the Specifications for the Manufacture of Carbon Steel Rails, recommended by the American Railway Engineering Association in 1915.

Each manufacturer naturally prefers to make rails under his own specifications, but the railroad companies feel that, in drawing up his specifications, the question of quantity (as well as quality) is liable to be given more weight by the manufacturer than is desirable.

Most of the Manufacturers' Specifications conform to nearly all of the requirements of the A. R. E. A. Specifications, but there are a few clauses in the latter which the Manufacturers have not yet been willing to accept without the payment by the Railroad Company of an extra amount in addition to the regular market price.

To attempt to include in this pamphlet all the various specifications extant, would serve no good purpose, but it will be interesting for the employes of any railroad company to compare the specifications under which their rail is being manufactured, with the specifications given herein, and see in what important points they differ.

The Specifications for *Open Hearth* Carbon Steel Rails are shown herein separately from those for *Bessemer* Carbon Steel Rails, as this makes for convenience in comparing and checking.

As the use of *Open Hearth* Steel is becoming more and more general, the specifications for that steel are given in full, whereas in the *Bessemer* Steel Specifications, those articles which are the same in both specifications are only referred to by number

of the corresponding article in the Open Hearth Specifications.

Each ingot must be considered as an individual or separate casting, and because one is sound is no proof that the others are also. One ingot may be a perfect casting, and the next one poured (of the same heat) may contain a deep pipe or large amount of segregation. Recent specifications recognize this fact and require a test on every ingot.

It is thought that these specifications are still not as strong as they should be on one point, that is, the test for chemical composition to show if much segregation is present in the finished rail, or if the chemical composition conforms to the specifications. Article 6 of the specifications provides for this test being made on a sample of hot metal taken from the ladle, whereas experience has shown that the chemistry of the finished rail may differ considerably from that found in the ladle.

With a view of overcoming these weak spots in the specifications two methods have been developed. In one method a chemical survey, and in the other an ocular inspection of the fractured surfaces, is made. Modifications of the A. R. E. A. specifications to cover the former method are shown on page 111, and for the latter method on page 109.

Contracts have been let for rollings under both methods and the results will be watched with great interest.

CHAPTER XX.

AMERICAN RAILWAY ENGINEERING ASSOCIATION.

1915 SPECIFICATIONS FOR *OPEN HEARTH* STEEL RAILS.

1. Inspectors representing the purchaser shall have free entry to the works of the manufacturer at all times while the contract is being executed, and shall have all reasonable facilities afforded them by the manufacturer to satisfy them that the rails have been made and loaded in accordance with the terms of the specifications.

2. All tests and inspections shall be made at the place of manufacture, prior to shipment, and shall be so conducted as not to interfere unnecessarily with the operation of the mill.

3. The material shall be steel made by the Open Hearth process, as provided by the contract.

4. The chemical composition of each heat of the steel from which the rails are rolled, determined as prescribed in Section 6, shall be within the following limits:

	Per Cent.	
Elements—	70 Lbs. and over, but under 85 Lbs.	85-100 Lbs., inclusive
Carbon	0.53 to 0.66	0.62 to 0.75
Phosphorus, not to exceed	0.04	0.04
Manganese	0.60 to 0.90	0.60 to 0.90
Silicon, not less than	0.10	0.10

When other acceptable deoxidizing agents are used, the minimum limit for Silicon will be omitted.

5. It is desired that the percentage of carbon in an entire order of rails shall average as high as the mean percentage between the upper and lower limits specified.

6. In order to ascertain whether the chemical composition is in accordance with the requirements, analyses shall be furnished as follows:

(a) See Bessemer specifications, page 105.

(b) The makers shall furnish the inspectors with a chemical analysis of the elements, carbon, manganese, silicon, phosphorus and sulphur, for each heat.

(c) On request of the inspector, the manufacturer shall furnish a portion of the test ingot for check analyses.

The analyses shall be made on drillings taken from the ladle test ingot not less than one-eighth inch beneath the surface.

7. **Tests shall be made to determine:**

(a) Ductility or toughness as opposed to brittleness.

(b) Soundness.

8. **The physical qualities shall be determined by the drop test.**

9. **The drop testing machine used shall be the standard of the American Railway Engineering Association.**

(a) The tup shall weigh 2,000 lbs., and have a striking face with a radius of five inches.

(b) The anvil block shall weigh 20,000 lbs., and be supported on springs.

(c) The supports for the test pieces shall be spaced three feet between centers and shall be a part of, and firmly secured to, the anvil. The bearing surfaces of the supports shall have a radius of five inches.

10. Drop tests shall be made on pieces of rail not less than four feet and not more than six feet long. These test pieces shall be cut from the top end of the top rail of the ingot, and marked on the base or head with gage marks one inch apart for three

inches each side of the center of the test piece, for measuring the ductility of the metal.

11. The temperature of the test pieces shall be between 60 and 100 degrees Fahrenheit.

12. The test piece shall preferably be placed base upwards on the supports, and be subjected to impact of the tup falling free from the following heights:

For 70-lb. rail ....16 feet
For 80, 85 and 90-lb. rail..........17 feet
For 100-lb. rail ....18 feet

13. (a) Under these impacts the rail under one or more blows shall show at least 6 per cent elongation for one inch, or 5 per cent each for two consecutive inches of the six-inch scale, marked as described in Sec. 10.

(b) A sufficient number of blows shall be given to determine the complete elongation of one out of every three test pieces of a heat.

14. It is desired that the permanent set after one blow under the drop test shall not exceed that in the following table, and a record shall be made of this information:

* Permanent set measured by middle ordinate in inches in a length of three feet.

Rail Section	Weight, Per Yard	Moment of Inertia	*Inch
A.R.A.—A	100 lbs.	48.94	1.45
A.R.A.—B	100 lbs.	41.30	1.80
A.R.A.—A	90 lbs.	38.70	1.65
A.R.A.—B	90 lbs.	32.30	2.00
A.R.A—A	80 lbs.	28.80	2.45
A.R.A.—B	80 lbs.	25.10	2.85
A.R.A.—A	70 lbs.	21.05	3.10
A.R.A.—B	70 lbs.	18.60	3.50

15. The test pieces which do not break under the first or subsequent blows shall be nicked and broken, to determine whether the interior metal is sound.

The words *interior defect,* used below, shall be interpreted to mean seams, laminations, cavities or interposed foreign matter made visible by the destruction tests, the saws or the drills.

16. This clause applies to Bessemer steel.

17. Test pieces shall be selected from the second, middle and last full ingot of each heat.

(a) If two of these test pieces do not break at at the first blow, and if both show the required elongation (Section 13), all of the rails of the heat shall be accepted, provided that none of the three test pieces when broken show interior defect.

(b) If two of the test pieces break at the first blow, or do not show the required elongation (Section 13), or if any of the three test pieces when broken show interior defect, all of the top rails from that heat shall be rejected.

(c) Second tests shall then be made from three test pieces selected by the inspector from the top end of any second rails of the same heat, preferably of the same ingots. If two of these test pieces do not break at the first blow, and if both show the required elongation (Section 13), all of the remainder of the rails of the heat shall be accepted, provided that none of the three test pieces when broken shows interior defect.

(d) If two of these test pieces break at the first blow, or do not show the required elongation (Section 13), or if any of the three test pieces when broken show interior defect, all of the second rails of the heat shall be rejected.

(e) Third tests shall then be made from three test pieces selected by the inspector from the top end of any third rails of the same heat, preferably of the same ingots. If two of these test pieces do not break at the first blow, and if both

show the required elongation (Section 13), all of the remainder of the rails of the heat shall be accepted, provided that none of the three test pieces when broken show interior defect.

(f) If two of these test pieces break at the first blow, or do not show the required elongation (Section 13), or if any of the three test pieces when broken show interior defect, all of the remainder of the rails from that heat shall be rejected.

18. No. 1 classification rails shall be free from injurious defects and flaws of all kinds.

19. (a) Rails, which, by reason of surface imperfections or for causes mentioned in Section 29 hereof, are not classed as No. 1 rails, will be accepted as No. 2 rails; but No. 2 rails which contain imperfections in such number or of such character as will, in the judgment of the inspector, render them unfit for recognized No. 2 uses, will not be accepted for shipment.

(b) No. 2 rails to the extent of 5 per cent of the whole order will be received. All rails accepted as No. 2 rails shall have the ends painted white and shall have two prick punch marks on the side of the web near the heat number near the end of the rail, so placed as not to be covered by the splice bars.

20. The entire process of manufacture shall be in accordance with the best current state of the art.

21. Bled ingots shall not be used.

22. There shall be sheared from the end of the bloom, formed from the top of the ingot, sufficient metal to secure sound rails.

23. The standard length of rails shall be 33 feet, at a temperature of 60 degrees Fahrenheit. Ten per cent of the entire order will be accepted in shorter lengths varying by 1 foot from 32 feet to 25 feet. A

variation of one-fourth inch from the specified lengths will be allowed, excepting that for 15 per cent of the order a variation of three-eighths inch from the specified lengths will be allowed. No. 1 rails less than 33 feet long shall be painted green on both ends.

24. The number of passes and speed of train shall be so regulated that on leaving the rolls at the final pass, the temperature of the rail will not exceed that which requires a shrinkage allowance at the hot saws, for a rail 33 feet in length and of 100 lbs. section, of six and three-fourths inches and one-eighth inch less for each ten pounds decrease in section.

25. The bars shall not be held for the purpose of reducing their temperature, nor shall any artificial means of cooling them be used after they leave the finishing pass. Rails, while on the cooling beds, shall be protected from snow and water.

26. The section of rails shall conform as accurately as possible to the template furnished by the railroad company. A variation in height of one-sixty-fourth inch less or one-thirty-second inch greater than the specified height, and one-sixteenth inch in width of flange, will be permitted; but no variation shall be allowed in the dimensions affecting the fit of the splice bars.

27. The weight of the rails specified in the order shall be maintained as nearly as possible, after complying with the preceding section. A variation of one-half of 1 per cent from the calculated weight of section, as applied to an entire order, will be allowed.

28. Rails accepted will be paid for according to actual weights.

29. (a) The hot straightening shall be carefully done, so that gagging under the cold presses will be reduced to a minimum. Any rail coming to the

straightening presses showing sharp kinks or greater camber than that indicated by a middle ordinate of 4 inches in 33 feet for A. R. A. type of sections, or 5 inches for A. S. C. E. type of sections, will be at once classed as a No. 2 rail. The distance between the supports of rails in the straightening presses shall not be less than 42 inches. The supports shall have flat surfaces and be out of wind.

(b) Rails heard to snap or check while being straightened shall be at once rejected.

30. Circular holes for joint bolts shall be drilled to conform to the drawing and dimensions furnished by the railroad company.

31.(a) All rails shall be smooth on the heads, straight in line and surface, and without any twists, waves or kinks. They shall be sawed square at the ends, a variation of not more than one-thirty-second inch being allowed; and burrs shall be carefully removed.

(b) Rails improperly drilled or straightened, or from which the burrs have not been removed, shall be rejected, but may be accepted after being properly finished.

(c) When any finished rail shows interior defects at either end or in any drilled hole the entire rail shall be rejected.

32. Rails shall be branded for identification in the following manner:

> (a) The name of the manufacturer, the month and year of manufacture, and the weight and type or section of rail shall be rolled in raised letters and figures on the side of the web. The type shall be marked by letters which signify the name by which it is known, as for example:

Sections of Am. Soc. of Civ. Engrs.....A.S.C.E.
Sections of Am. Ry. Assn........ { R. A.—A. / R. A.—B.
Sections of Am. Ry. Eng. Assocn.........R.E.

(b) The number of the heat and letter indicating the portion of the ingot from which the rail was made shall be plainly stamped on the web of each rail where it will not be covered by the joint bars. The top rails shall be lettered *A* and the succeeding ones *B*, *C*, *D*, etc., consecutively; but in case of a top discard of from 20 to 35 per cent, the letter *A* will be omitted, the top rail becoming *B*. If the top discard be greater than 35 per cent the letter *B* shall be omitted, the top rail becoming *C*.

(c) Rails shall be branded or stamped *O-H* in addition to the other marks.

(d) All markings of rails shall be done so effectively that the marks may be read as long as the rails are in service.

33. All classes of rails shall be kept separate from each other.

34. Rails shall be carefully handled and loaded in such a manner as not to injure them.

CHAPTER XXI.

AMERICAN RAILWAY ENGINEERING ASSOCIATION.

1915 SPECIFICATIONS FOR *BESSEMER STEEL RAIL*

1. Same as Open Hearth Specifications, page —.

2. Same as Open Hearth Specifications, page —.

3. The material shall be steel, made by the Bessemer process, as provided by the contract.

4. The chemical composition of each heat of the steel from which the rails are rolled, determined as prescribed in Section 6, shall be within the following limits:

	Per Cent	
Elements —	70 Lbs. and over, but under 85 Lbs.	85-100 Lbs., inclusive
Carbon	0.40 to 0.50	0.45 to 0.55
Phosphorus, not to exceed.	0.10	0.10
Manganese	0.80 to 1.10	0.80 to 1.10
Silicon, not less than	0.10	0.10

When other acceptable deoxidizing agents are used, the minimum limit for Silicon will be omitted.

5. Same as Open Hearth specifications, page 97.

6. In order to ascertain whether the chemical composition is in accordance with the requirements, analyses shall be furnished as follows:

(a) The manufacturer shall furnish to the inspector daily, carbon determinations for each heat before the rails are shipped, and two chemical analyses every twenty-four hours representing the average of the elements carbon, manganese, silicon, phosphorus and sulphur contained in the steel, one for each day and night turn respectively. These analyses shall be made on drillings taken from the ladle test ingot not less than one-eighth inch beneath the surface.

(b) This clause applies to Open Hearth steel only.

(c) Same as Open Hearth Specifications, page 98.

7. Same as Open Hearth Specifications, page 98.
8. Same as Open Hearth Specifications, page 98.
9. Same as Open Hearth Specifications, page 98.
10. Same as Open Hearth Specifications, page 98.
11. Same as Open Hearth Specifications, page 99.
12. Same as Open Hearth Specifications, page 99.
13. (a) Same as Open Hearth Specifications, page 99.

(b) A sufficient number of blows shall be given to determine the complete elongation of the test piece of at least every fifth heat of steel.

14. It is desired that the permanent set after one blow under the drop test shall not exceed that in the following table, and a record shall be made of this information:

*Permanent set measured by middle ordinate in inches in a length of three feet.

Rail Section	Weight, Per Yard	Moment of Inertia	*Inch
A.R.A.—A	100 lbs.	48.94	1.65
A.R.A.—B	100 lbs.	41.30	2.05
A.R.A.—A	90 lbs.	38.70	1.90
A.R.A.—B	90 lbs.	32.30	2.20
A.R.A.—A	80 lbs.	28.80	2.85
A.R.A.—B	80 lbs.	25.10	3.15
A.R.A.—A	70 lbs.	21.05	3.50
A.R.A—B	70 lbs.	18.60	3.85

15. Same as Open Hearth.
16. One piece shall be tested from each heat.

(a) If the test piece does not break at the first blow and shows the required elongation (Section 13), all of the rails of the heat shall be accepted, provided that the test piece when broken does not show interior defect.

(b) If the test piece breaks at the first blow, or does not show the required elongation (Section 13), or if the test piece does not break and shows the required elongation, but when broken shows interior defect, all of the top rails from that heat shall be rejected.

(c) A second test shall then be made of a test piece selected by the inspector from the top end of any second rail of the same heat, preferably of the same ingot. If the test piece does not break at the first blow, and shows the required elongation (Section 13), all of the remainder of the rails of the heat shall be accepted, provided that the test piece when broken does not show interior defect.

(d) If the test piece breaks at the first blow, or does not show the required elongation (Section 13), or if the test piece does not break and shows the required elongation, but when broken shows interior defect, all of the second rails from that heat shall be rejected.

(e) A third test shall then be made of a test piece selected by the inspector from the top end of any third rail of the same heat, preferably of the same ingot. If the test piece does not break at the first blow and shows the required elongation (Section 13), all of the remainder of the rails of the heat shall be accepted, provided that the test piece when broken does not show interior defect.

(f) If the test piece breaks at the first blow, or does not show the required elongation (Section 13), or if the test piece does not break and shows the required elongation, but when broken shows interior defect, all of the remainder of the rails from that heat shall be rejected.

17. This clause applies to Open Hearth Specifications only.

18. Same as Open Hearth Specifications, page 101.

19. Same as Open Hearth Specifications, page 101.

20. Same as Open Hearth Specifications, page 101.

Bessemer Specifications.

21. Same as Open Hearth Specifications, page 101.

22. Same as Open Hearth Specifications, page 101.

23. Same as Open Hearth Specifications, page 101.

24. Same as Open Hearth Specifications, page 102.

25. Same as Open Hearth Specifications, page 102.

26. Same as Open Hearth Specifications, page 102.

27. Same as Open Hearth Specifications, page 102.

28. Same as Open Hearth Specifications, page 102.

29. Same as Open Hearth Specifications, page 102.

30. Same as Open Hearth Specifications, page 103.

31. Same as Open Hearth Specifications, page 103.

32. (a) Same as Open Hearth Specifications, page 103.

(b) Same as Open Hearth Specifications, page 104.

(c) This clause applies to Open Hearth Specifications only.

(d) Same as Open Hearth Specifications, page 104.

33. Same as Open Hearth Specifications, page 104.

34. Same as Open Hearth Specifications, page 104.

CHAPTER XXII.

MODIFICATION OF SPECIFICATIONS SO AS TO REQUIRE NICK-AND-BREAK TEST ON EACH INGOT.

17. Test pieces shall be selected from the second, middle and last full ingot of each Open Hearth heat.

(a) If two of these test pieces do not break at the first blow, and if both show the required elongation (Section 13), all of the rails of the heat shall be accepted, except as provided by Clause (g).

(b) If two of the test pieces break at the first blow or do not show the required elongation Section (13), all of the top rails from that heat shall be rejected.

(c) Second tests shall then be made from three test pieces selected by the inspector from the top end of any second rails of the same heat, preferably of the same ingots. If two of these test pieces do not break at the first blow and if both show the required elongation (Section 13), all of the remainder of the rails of the heat shall be accepted, except as provided by Clause (g).

(d) If two of these test pieces break at the first blow or do not show the required elongation (Section 13), all of the second rails of the heat shall be rejected.

(e) Third tests shall then be made from three test pieces selected by the inspector from the top end of any third rails of the same heat, preferably of the same ingots. If two of these test pieces do not break at the first blow, and if both show the required elongation (Section 13), all of the remainder of the rails of the heat shall be accepted, except as provided by Clause (g).

(f) If two of these test pieces break at the first blow, or do not show the required elongation (Section 13), all of the remainder of the rails from that heat shall be rejected.

(g) The test pieces which have successfully withstood the drop test and also a piece representing the top crop end of all other top rails shall be nicked and broken. If the fracture shows interior defect the *A* or top rail of the

ingot shall be rejected and a piece cut from its bottom end to represent the *B* or second rail of the same ingot. This piece shall then be nicked and broken, and if its fracture shows interior defect the rail represented shall be rejected. The testing by nicking and breaking shall proceed progressively in this manner on all the rails of each ingot, if necessary, and they shall be accepted or rejected, according as the fracture of the test piece representing them shows interior defect.

32. (e) Each rail must be stamped with a number to indicate the ingot from which it was rolled, so as to permit of identification with the other rails of the same ingot.

CHAPTER XXIII.

MODIFICATION OF SPECIFICATIONS SO AS TO REQUIRE CHEMICAL ANALYSIS OF FINISHED RAIL.

(*Adopted by Penna. R. R., 1915.*)

In order to ascertain whether the chemical composition is in accordance with the requirements, analyses shall be furnished as follows:

(a) For the Bessemer process, the manufacturer shall furnish to the inspector daily, the carbon determination for each melt before the rails are shipped, and two chemical analyses every twenty-four hours, representing the average of the elements, carbon, manganese, silicon, phosphorus and sulphur, contained in the steel, one for each day and night turn, respectively. The analyses shall be made on drillings taken from the ladle test ingot not less than ⅛ inch beneath the surface.

(b) For the Open Hearth process, the makers shall furnish the inspector with a chemical analysis of the elements, carbon, manganese, silicon, phosphorus and sulphur, for each melt.

(c) For the Open Hearth process, a check analysis will be made by the purchaser of a piece

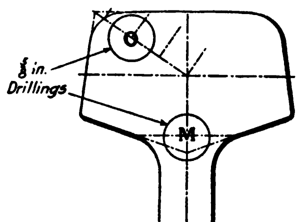

Fig. 9.

of rail representing a melt, after the rails from that melt have passed the physical requirements. On request of the inspector, and in his presence, the manufacturer shall furnish from one of the drop test pieces representing the melt, drillings satisfactory to the inspector, taken with a ⅝-inch flat drill, parallel to the axis of the rail,

at a point one-third of the distance from the upper corner to the center of the head, as shown at location *O* in Fig. 9. The analysis from these drillings shall conform to the chemical requirements specified, and failure to meet these requirements shall be sufficient cause for the rejection of the entire melt.

(d) For the Open Hearth process, after the rail has passed the physical requirements, additional drillings will be taken from the same rail, and in the same manner as specified in clause (c), at the junction of the head and web, as shown at location *M* in Fig. 9. The carbon determination from these drillings shall be within 12 per cent of the amount found at location *O*. If the test from the top rails fails to meet this requirement, all the top rails from the melt shall be rejected, and a similar determination shall be made from location *M* of a second rail. If this test fails all the second rails from the melt shall be rejected, and a similar determination shall be made from location *M* of a third rail. If this test fails all the remaining rails from the melt shall be rejected.

(e) If, however, the segregation found at location *M* in any rail in a rolling exceeds 25 per cent, when determined as provided for in clause (d), the progressive testing of the second and third rails will not be permitted on any subsequent melts; but on such melts the failure of the top rail to pass the requirements provided for in clause (d) will cause the rejection of the entire heat.

NOTES.

1. When the analysis for carbon by the mill chemists and by the railroad chemists do not agree, a tolerance of two points below the minimum or two points above the maximum will be allowed to cover such variation before condemnation.

2. Where it is necessary to test rails lower than the first rail, the bottom of the first rail, in lieu of the top of the second rail; and the bottom of the second rail, in lieu of the top of the third rail, will be accepted, if preferred by the manufacturer.

CHAPTER XXIV.

TOLERANCES.

Metallic products of large size cannot readily be cast or rolled to exact dimensions specified, but where such results are desired must be sent to the machine shop, and brought to exact size by means of planers, lathes, etc.; in the case of rails, such machine shop work would be very expensive.

Efforts to have the rails rolled to the exact dimensions specified, would also necessitate changing rolls in the rolling-mill very often, and as soon as the old rolls showed any signs of wear.

These additional expenses would not be warranted by the benefits that might be gained, therefore, as a matter of economy, small variations or departures from the plans and specifications are usually permitted; these variations are generally called *"permissible tolerances."*

A perusal of the specifications will show the usual tolerances embodied therein, but for convenience they are summarized in this chapter, so that the Trackman will understand clearly just what variations from plans and specifications he may expect to find in new rail delivered him.

LENGTH.

The present standard length of rail is 33 feet, but usually 10 per cent of the entire order will be accepted in shorter lengths, varying by one foot from 32 feet to and including 25 feet, or in some cases 24 feet.

Most specifications permit a variation of ¼ inch from the specified lengths, with a variation of ⅜ inch for 15 per cent of the total order.

Some specifications require the ends of the rails to be milled, and thus brought to exact length.

Tolerances.

ENDS OF RAIL.

Specifications usually provide that the ends of rails shall be sawed square, but permit a variation of not more than 1/32 inch off square in any direction. Rails that are slightly *"head long,"* that is, have the bases at the ends undercut, are preferable to those in the opposite condition.

Where specifications require ends of rails to be milled in order to bring the rails to exact length, they also specify that the ends shall be milled square, both laterally and vertically; with the higher sections of rails an undercut of 1/32 inch is usually permitted.

HEIGHT.

The height of the rail section may be 1/64 inch less or 1/32 inch greater than that specified.

BASE.

The total width of the base may be 1/16 inch less or greater than specified; convex bases, called *"rocky bottoms,"* are not desired, and should not be accepted at the mill.

FISHING.

Most specifications permit no variation in those dimensions which affect the fit of the joint bars. Some specifications, however, allow 1/16 inch variation, either way, in the horizontal location of the fishing template; this is generally regarded as too much allowance, and better results are obtained where a total variation of less than 1/16 inch is insisted upon.

DRILLING.

A variation of 1/32 inch in the location of bolt holes is usually permitted, and the holes may be 1/32 inch larger than specified, but no smaller. In recent

specifications of the railroad companies efforts have been made to have the drilling conform exactly to the specifications.

SECOND QUALITY RAILS.

Nearly all specifications provide for the acceptance of second quality rails to the extent of 5 per cent of the total order; this 5 per cent may be included in or be additional to the total tonnage ordered.

No. 2 rails are always painted white on both ends, and have two prick punch marks on the web near the bolt holes.

WEIGHT.

On account of the permissible tolerances it is impossible to roll exactly to the weight of rail ordered, and a total variation of one-half of one per cent, over or under the theoretical weight, on the entire order is usually permitted.

In addition to the foregoing tolerances, other variations, which do not ordinarily affect track conditions, may exist.

The width of head, thickness of web, and thickness of flange, may vary slightly from specified dimensions, but these can usually be controlled by the manufacturer and the inspector.

It is important to control the curve of top of head, and it is frequently difficult to maintain it as desired. Flat-headed rails are the result of failure to keep a full radius; on the other hand, if allowed to become too full, a slight ridge or welt, about one-half inch wide, is left in the center of the head. Flat-headed rails should be avoided, but the ridge in the center is generally accepted as a sign of good-rolling conditions, and as it soon disappears under traffic, such rails should not be criticised unless the ridge is too pronounced.

PART VII

BRANDING AND STAMPING.

INTRODUCTION.

BRAND:

Every rail manufactured by each mill is branded with

The name of the manufacturer,

A number or abbreviation indicating rail section and weight,

The month and year of manufacture, and

If the metal is *open hearth* steel the letters *OH are added.*

Square block letters and figures about one inch high are commonly used, and as these are cut into one of the rolls of the last pass, the brand will always appear SLIGHTLY RAISED at regular intervals on the web of the rail.

The month is generally shown by Roman numerals, as VII for July, and sometimes by a series of |'s, as | | | | | for May.

The section is usually shown by number or combination of number and letters, such as 9020, 902, 90RA, etc., instead of 90 ARA-A; each mill has special numbers which it uses to designate the different rail sections.

The rail failure reports should show under questions 2 and 3, the marking of the brand EXACTLY as it appears on the web of the rail.

STAMP:

Every rail is stamped with

The number representing the heat, blow, or melt of steel, and

A letter to indicate the position of the rail in the ingot;

With rail rolled under specifications requiring a test on every ingot (such as those shown on

page 109) it is also necessary to stamp an additional number on each rail to indicate the ingot from which it was rolled, so that all the rails from each ingot can be identified.

There are usually from four to eight rails, depending upon the weight, rolled from each ingot, so that the letters usually run from *A* to *G*.

The heat number is the number given by the mill to the contents of the furnace or converter in which each melt of steel is made.

The specifications require certain tests to be made on each melt, and a record of the chemical tests of each melt, and of the physical tests on the rail made therefrom, is kept under this number. As this number is constantly changing it cannot be placed on the rolls in the rolling mill.

The stamping is therefore done (on the web of the rail) with dies while the rail is still red hot, but after it has been completely rolled and sawed to length. The methods of branding and stamping the necessary data on the rail are not uniform. Each mill uses different symbols to abbreviate the information, and places these abbreviations at different points on the web of the rail, and in varying locations with reference to each other.

Except at the Lorain mill, the heat number is always applied by dies carried on a wheel which revolves, so that when brought into contact with the moving rail, the numerals on the face of the dies are stamped on the web. It may be repeated therefore several times on the rail length, or it may be shown only once or twice, according to mechanical conditions at the mill.

The letter showing the position of the rail in the ingot is sometimes stamped on by hand, in which case a die is held on the rail and struck with a

hammer, but generally it is applied by the same or another machine that stamps the heat number.

Of course, if the dies become worn or slightly twisted the figures and letters are bound to be indistinct.

All rails rolled since 1912 have the *brand* on one side of the web, and the *stamp* on the other side. Remembering that the brand *always* appears in RAISED LETTERS, and the heat number and rail letter in SUNKEN LETTERS AND FIGURES, no confusion of the two should arise.

The trackman should familiarize himself with the particular brands and stamps of all rail in service on his territory, and for convenience, a blank form is given on which may be entered the abbreviations and symbols for such rail.

CHAPTER XXV.

AMERICAN RAIL MILLS—STAMPING PRACTICE.

ALGOMA STEEL CO.

Bessemer heat numbers contain from one to five figures and Open Hearth heat numbers generally four figures; these are stamped at least three times on the unbranded side of the web.

BETHLEHEM STEEL CO.

There are always five figures in the heat number, which is stamped at least once on the unbranded side of the web, generally near the center.

Prior to 1914 a letter was placed in front of the heat number to indicate which furnace furnished the metal; this should not be confused with the rail letter which follows the heat number and is stamped by the same machine. Typical stamping would be B18945 C, which would mean a C rail from heat number 18945 from furnace B. The furnace letter has been omitted since 1914.

CAMBRIA STEEL CO.

Bessemer heat numbers may contain from one to five figures, open hearth heats always contain five figures; these are stamped at least twice on the unbranded side of the web.

The rail letter is stamped by a separate machine so that it usually appears about six times on the rail length and can therefore be easily located.

Prior to 1908 the brand and heat number were placed on same side of web.

CARNEGIE STEEL CO. (Edgar Thompson Works)

Bessemer heat numbers may contain from one to five figures, open hearth heats always contain five figures; these are stamped at least three times on the unbranded side of the web.

Formerly, the rail letter was stamped on by hand, generally twice near one end, but the stamping is now done by the heat-numbering machine.

Prior to 1913 a new series of numbers (each starting with number one) were used for Bessemer heats beginning with each quarter, so that it was possible to have four heats of the same number each year, and the month must therefore be given in order to identify the heat.

COLORADO FUEL AND IRON CO.

There are from one to four figures in the heat number, which is stamped four times on the unbranded side of the web.

The rail letter is stamped on by hand at least once near the end of the rail so that it will be near the joints, and may be upside down.

Prior to 1912 the heat number was stamped on the branded side of the web at least twice, and as the branding and stamping sometimes came close together some confusion was caused and the practice was therefore discontinued.

DOMINION IRON & STEEL CO.

There are always four figures in the heat number, which is stamped at least twice on the unbranded side of the web.

The rail letter is stamped on by hand at least once near the end of the rail so that it will be near the joints.

ILLINOIS STEEL CO. (Gary Works).

There are always five figures in the heat number, which is stamped at least twice on the unbranded side of the web.

The rail letter is stamped on by hand by the same machine that stamps the heat number, and it will therefore appear as often as the heat number and following

it; the distance between the last figure of the heat number and the letter may assist in deciphering the letter, as this distance increases regularly for each succeeding letter; e. g., 16897 B and 16897   G.

ILLINOIS STEEL CO. (South Works).

There may be from one to five figures in the heat number, in other respects the stamping is identical with that at Gary.

LACKAWANNA STEEL CO.

There may be from one to five figures in the heat number, which is stamped at least once on the unbranded side of the web, usually near the middle of the rail.

The rail letter is stamped on by a separate machine at least twice, generally appearing near the heat number.

On open hearth rail the letters OH may be stamped to one side of the heat number.

LORAIN STEEL CO.

There are always four figures in the heat number, which is stamped by hand near one end of the rail so that it will be near the joints.

Unless specially required rail letters are not stamped on rail made at this mill.

MARYLAND STEEL CO.

Bessemer heat numbers may contain from one to five figures, open hearth heats always contain four figures; these are stamped at least twice on the unbranded side of the web.

In front of the heat number a character is used which, on Bessemer steel, indicates the ingot number, and on Open Hearth steel, indicates the number of the furnace; this character should not be confused with the heat number.

The rail letter immediately follows the last figure of the heat number, being added by the same machine; e. g., 4167D.

MONTEREY IRON & STEEL CO.

There are always four figures in the heat number, which is stamped at least three times on the unbranded side of the web.

The rail letter is stamped on by the same machine and immediately follows the last figure of the heat number.

PENNSYLVANIA STEEL CO.

There are either four or five figures in the heat number, which, prior to 1915, was stamped on the branded side of the web at least twice; the rail letter was stamped on by a different machine, at least once, generally near the center of the rail. Under this method it was possible for the branding and stamping to come close together and cause confusion; this practice has been changed, and the number and letter are now stamped by the same machine on the unbranded side of the web.

TENNESSEE COAL, IRON & RAILROAD CO.

There are always five figures in the heat number, which is stamped on the unbranded side of the web at least twice.

The rail letter is stamped on by the same machine, but appears in front of the heat number.

CHAPTER XXVI.

BRANDS AND STAMPS ON RAIL IN SERVICE IN TRACKS OF

....R. COMPANY, ...19....

Weight of Rail	Section	Kind of Steel	Years Rolled	Manufactured by	Typical Brand	Typical Stamp
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....

CHAPTER XXVI.

BRANDS AND STAMPS ON RAIL IN SERVICE IN TRACKS OF

....R. COMPANY, ...19....

Weight of Rail	Section	Kind of Steel	Years Rolled	Manufactured by	Typical Brand	Typical Stamp

PART VIII
RAIL SECTIONS.

INTRODUCTION.

Following chapters show dimensions of, and other data concerning, the various rail sections recommended for general use by the

American Society of Civil Engineers in 1893,
American Railway Association in 1908, and
American Railway Engineering Association in 1915.

Special sections have, from time to time, been adopted by individual railroads, with a view of meeting special conditions of their service and locality. The principal characteristics of those sections are given on pages 140 to 142 and on page 144 is a blank form on which can be entered additional data concerning those or other special sections.

In their study of rail sections, and their relation to manufacturing processes, the committees of the various Associations have, from time to time, enunciated the following principles that govern the design of rail sections:

1. Metal in head and web to be well balanced in order to
   - (a) Obtain uniformity in cooling and thus reduce internal strains,
   - (b) Have rail as straight as possible when cooled so as to avoid excessive cold straightening,
   - (c) Obtain uniformity and homogeneity of metal in head and base after rolling.
2. Outer edges of base to be thick enough to
   - (a) Avoid rapid cooling and difficulty in filling out to full width without development of flaws,
   - (b) Permit entire section to be rolled at low temperatures.

3. As fineness of grain is governed by the work done as the heat decreases, the section should be designed to obtain the maximum amount of work
   (a) On the entire section,
   (b) Especially on the head, in order to get the best wearing qualities.
4. Sections should be so proportioned as to have
   (a) Greatest amount of stiffness and strength,
   (b) Sufficient shearing strength in the head,
   (c) As great a depth of joint bar as possible,
   (d) Sufficient shoulder for bearing surface on joint bar,
   (e) Sides of head vertical or nearly so,
   (f) Neutral axis located close to center line of bolt holes,
   (g) Ratio of section modulus to area of section as high as possible.
5. Following limits as to dimensions are considered advisable:
   (a) Width of base to be ½ in. less than height,
   (b) Fishing angles to be between 13 and 15 degrees,
   (c) Radii of under corner of head and top and bottom corners of base to be as small as practicable with the lower rolling temperatures,
   (d) Radii of fillets connecting web with head and base to be as large as possible for reinforcement purposes, but not conflict with 4- (d),
   (e) Radii of top corners of head should not be less than ⅜ inch so long as present M. C. B. wheel contour holds.

CHAPTER XXVII.

RAIL SECTIONS RECOMMENDED BY AMERICAN RAILWAY ENGINEERING ASSOCIATION IN 1915.

DIMENSIONS. (In Inches.)

	90 lb.	100 lb.	110 lb.	120 lb.	130 lb.	140 lb.
Width (of base)	5–1/8	5–3/8	5–1/2	5–3/4	6	6–1/4
Height	5–5/8	6	6–1/4	6–1/2	6–3/4	7
Head, width of	2–9/16	2–11/16	2–25/32	2–7/8	2–15/16	3
Head, depth of	1–15/32	1–21/32	1–23/32	1–25/32	1–27/32	1–29/32
Web, thickness of	9/16	9/16	19/32	5/8	21/32	11/16
Web, depth of	3–5/32	3–9/32	3–13/32	3–17/32	3–11/16	3–27/32
Base, depth of	1	1–1/16	1–1/8	1–3/16	1–7/32	1–1/4
Fillet radia, head and web	3/8	3/8	3/8	3/8	1/2	1/2
Fillet radia, base and web	3/8	5/8	5/8	5/8	3/4	3/4
Neutral axis, Dist. to base	2–35/64	2–3/4	2–53/64	2–59/64	3–1/32	3–9/64
Min. web width Dist. to base	2–29/32	2–31/32	3–1/8	3–1/4	3–3/8	3–1/2

FEATURES COMMON TO ALL A. R. E. A. SECTIONS.

Curve of top of head........................14 inch rad.
Curve of side of web........................14 inch rad.
Curve of top corners of head........................3/8 inch rad.
Curve of bottom corners of head and top and bottom corners of base..........1/16 inch rad.
Side slope of head........................1 to 16
Fishing slopes........................4 to 1

PHYSICAL CHARACTERISTICS.

	90 lb.	100 lb.	110 lb.	120 lb.	130 lb.	140 lb.
Actual weight pounds.........	89.96	101.49	110.36	120.87	129.64	138.52
Area of head, square inches....	3.20	3.80	4.04	4.40	4.63	4.93
Head—Per cent of total area...	36.2	38.2	37.4	37.1	36.4	36.3
Area of web, square inches....	3.12	2.25	2.49	2.69	3.02	3.28
Web—Per cent of total area...	24.0	22.6	23.0	22.7	23.8	24.1
Area of base, square inches....	3.50	3.90	4.29	4.76	5.06	5.37
Base—Per cent of total area...	39.8	39.2	39.6	40.2	39.8	39.6
Total area, square inches......	8.82	9.95	10.82	11.85	12.71	13.58
Moment of inertia.............	38.70	49.00	57.00	67.60	77.40	89.20
Section Modulus—Head	12.56	15.10	16.70	18.90	20.80	23.10
Section Modulus—Base	15.23	17.80	20.10	23.10	25.60	28.40
Ratio—M. I. to area...........	4.39	4.92	5.27	5.71	6.09	6.56
Ratio—Sec. Mod. to area......	1.42	1.52	1.55	1.59	1.64	1.70

NOTE.—While sections for 130 lbs, and 140 lb. rail are submitted, the A. R. E. Association neither considers them necessary nor recommends their use, at this time.

CHAPTER XXVIII.

RAIL SECTIONS RECOMMENDED BY THE AMERICAN RAILWAY ASSOCIATION IN 1908.

TYPE "A" SECTIONS.

DIMENSIONS. (In Inches.)

	60 lb.	70 lb.	80 lb.	90 lb.	100 lb.
Width (of base)	4	4–1/4	4–5/8	5–1/8	5–1/2
Height	4–1/2	4–3/4	5–1/8	5–5/8	6
Head, width of	2–1/4	2–3/8	2–1/2	2–9/16	2–3/4
Head, depth of	1–15/64	1–11/32	1–7/16	1–15/32	1–9/16
Web, thickness of	15/32	1/2	33/64	9/16	9/16
Web, depth of	2–29/64	2–1/2	2–23/32	3–5/32	3–3/8
Base, depth of	13/16	29/32	31/32	1	1–1/16
Fillet radia, head and web	3/8	3/8	3/8	3/8	3/8
Fillet radia, base and web	3/8	3/8	3/8	3/8	3/8
Neutral axis, distance to base	2.13	2.20	2.31	2.54	2.75
Min. web width, distance to base	2–17/64	2–13/32	2–9/16	2–29/32	2–15/16

FEATURES COMMON TO ALL A. R. A.—A. SECTIONS:

Curve of top of head......14 inches radius
Curve of side of web......14 inches radius
Curve of top corners of head......3/8 inches radius
Curve of bottom corners of head and top and bottom corners of base..1/16 inches radius
Side slope of head......1 to 16
Fishing slopes......4 to 1
Fillets connecting web with head and base......3/8 inches radius

PHYSICAL CHARACTERISTICS.

	60 lb.	70 lb.	80 lb.	90 lb.	100 lb.
Actual weight, pounds				89.96	
Area of head, square inches	2.21	2.68	3.05	3.20	3.64
Head—Per cent of total area	37.7	39.3	38.8	36.2	36.9
Area of web, square inches	1.41	1.49	1.65	2.12	2.29
Web—Per cent of total area	24.1	21.8	21.0	24.0	23.4
Area of base, square inches	2.24	2.65	3.16	3.50	3.91
Base—Per cent of total area	38.2	38.9	40.2	39.8	39.7
Total Area, square inches	5.86	6.82	7.86	8.82	9.84
Moment of inertia	15.41	21.05	28.80	38.70	48.94
Section Modulus—Head	6.50	8.21	10.24	12.56	15.04
Section Modulus—Base	7.24	9.51	12.46	15.23	17.78
Ratio—Moment of inertia to area	2.63	3.09	3.66	4.39	4.97
Ratio—Section Modulus to area	1.11	1.20	1.30	1.42	1.53

CHAPTER XXIX.

RAIL SECTIONS RECOMMENDED BY THE AMERICAN RAILWAY ASSOCIATION IN 1908.

TYPE "B" SECTIONS.

DIMENSIONS. (In Inches.)

	60 lb.	70 lb.	80 lb.	90 lb.	100 lb.
Width (of base)	3–11/16	4–3/64	4–7/16	4–49/64	5–9/64
Height	4–3/16	4–35/64	4–15/16	5–17/64	5–41/64
Head, width of	2–1/8	2–3/8	2–7/16	2–9/16	2–21/32
Head, depth of	1–1/4	1–23/64	1–15/32	1–39/64	1–45/64
Web, thickness of	31/64	33/64	35/64	9/16	9/16
Web, depth of	2–1/16	2–17/64	2–15/32	2–5/8	2–55/64
Base, depth of	7/8	59/64	1	1–1/32	1–5/64
Fillet radia, head with web	5/16	5/16	5/16	5/16	5/16
Fillet radia, base with web	5/16	5/16	5/16	5/16	5/16
Neutral axis, distance from base	1–61/64	2–5/32	2–35/128	2–57/128	2–5/8
Min. web width, distance from base	1–29/32	2–7/128	2–15/64	2–11/32	2–65/128

FEATURES COMMON TO ALL A. R. A.—B. SECTIONS:

Curve of top of head..12 inches radius
Curve of side of web..12 inches radius
Curve of top corners of head....................................3/8 inches radius
Curve of bottom corners of head and top and bottom corners of base..1/16 inches radius
Angle of sides of head with vertical.......................... 3 degrees
Fishing angles..13 degrees
Fillets connecting web with head and base........................5/16 inches radius

PHYSICAL CHARACTERISTICS.

	60 lb.	70 lb.	80 lb.	90 lb.	100 lb.
Actual weight, pounds					
Area of head, square inches	2.28	2.76	3.07	3.56	3.95
Head—Per cent of total area	38.8	40.1	38.8	40.1	40.2
Area of web, square inches	1.14	1.34	1.54	1.70	1.89
Web—Per cent of total area	19.4	19.5	19.5	19.2	19.2
Area of base, square inches	2.45	2.79	3.30	3.61	4.01
Base—Per cent of total area	41.8	40.4	41.7	40.7	40.6
Total area, square inches	5.87	6.89	7.91	8.87	9.85
Moment of inertia	13.3	18.6	25.1	32.3	41.3
Section Modulus—Head	5.90	7.79	9.38	11.45	13.70
Section Modulus—Base	6.80	8.62	11.08	13.21	15.74
Ratio—Moment of inertia to area	2.26	2.70	3.17	3.64	4.19
Ratio—Section Modulus to area	1.00	1.13	1.19	1.29	1.39

CHAPTER XXX.

RAIL SECTIONS RECOMMENDED BY THE AMERICAN SOCIETY OF CIVIL ENGINEERS, 1893.

DIMENSIONS. (In Inches.)

	40 lb.	45 lb.	50 lb.	55 lb.	60 lb.	65 lb.	70 lb.
Width (of base).....	3-1/2	3-11/16	3-7/8	4-1/16	4-1/4	4-7/16	4-5/8
Height	3-1/2	3-11/16	3-7/8	4-1/16	4-1/4	4-7/16	4-5/8
Head, width of......	1-7/8	2	2-1/8	2-1/4	2-3/8	2-13/32	2-7/16
Head, depth of......	1-1/64	1-1/16	1-1/8	1-11/64	1-7/32	1-9/32	1-11/32
Web, thickness of...	25/64	27/64	7/16	15/32	31/64	1/2	33/64
Web, depth of......	1-55/64	1-31/32	2-1/16	2-11/64	2-17/64	2-3/8	2-15/32
Base, depth of......	5/8	21/32	11/16	23/32	49/64	25/32	13/16
Fillet radia, head with web	1/4	1/4	1/4	1/4	1/4	1/4	1/4
Fillet radia, base with web	1/4	1/4	1/4	1/4	1/4	1/4	1/4
Neutral Axis, dist. to base	1.67	1.76	1.88	1.97	2.05	2.14	2.22
Min. web width, dist. to base	1-71/128	1-41/64	1-23/32	1-103/128	1-115/128	1-31/32	2-3/64

	75 lb.	80 lb.	85 lb.	90 lb.	95 lb.	100 lb.
Width (of base)	4–13/16	5	5–3/16	5–3/8	5–9/16	5–3/4
Height	4–13/16	5	5–3/16	5–3/8	5–9/16	5–3/4
Head, width of	2–15/32	2–1/2	2–9/16	2–5/8	2–11/16	2–3/4
Head, depth of	1–27/64	1–1/2	1–35/64	1–19/32	1–41/64	1–45/64
Web, thickness of	17/32	35/64	9/16	9/16	9/16	9/16
Web, depth of	2–35/64	2–5/8	2–3/4	2–55/64	2–63/64	3–5/64
Base, depth of	27/32	7/8	57/64	59/64	15/16	31/32
Fillet radia, head with web	1/4	1/4	1/4	1/4	1/4	1/4
Fillet radia, base with web	1/4	1/4	1/4	1/4	1/4	1/4
Neutral axis, dist. to base	2.30	2.38	2.47	2.55	....	2.73
Min. web width, dist. to base	2–15/128	2–3/16	2–17/64	2–45/128	....	2–65/128

CHAPTER XXVII.

RAIL SECTIONS RECOMMENDED BY AMERICAN RAILWAY ENGINEERING ASSOCIATION IN 1915.

DIMENSIONS. (In Inches.)

	90 lb.	100 lb.	110 lb.	120 lb.	130 lb.	140 lb.
Width (of base)	5–1/8	5–3/8	5–1/2	5–3/4	6	6–1/4
Height	5–5/8	6	6–1/4	6–1/2	6–3/4	7
Head, width of	2–9/16	2–11/16	2–25/32	2–7/8	2–15/16	3
Head, depth of	1–15/32	1–21/32	1–23/32	1–25/32	1–27/32	1–29/32
Web, thickness of	9/16	9/16	19/32	5/8	21/32	11/16
Web, depth of	3–5/32	3–9/32	3–13/32	3–17/32	3–11/16	3–27/32
Base, depth of	1	1–1/16	1–1/8	1–3/16	1–7/32	1–1/4
Fillet radia, head and web	3/8	3/8	3/8	3/8	1/2	1/2
Fillet radia, base and web	3/8	5/8	5/8	5/8	3/4	3/4
Neutral axis, Dist. to base	2–35/64	2–3/4	2–53/64	2–59/64	3–1/32	3–9/64
Min. web width Dist. to base	2–29/32	2–31/32	3–1/8	3–1/4	3–3/8	3–1/2

FEATURES COMMON TO ALL A. R. E. A. SECTIONS.

Curve of top of head .... 14 inch rad.
Curve of side of web .... 14 inch rad.
Curve of top corners of head .... 3/8 inch rad.
Curve of bottom corners of head and top and bottom corners of base .... 1/16 inch rad.
Side slope of head .... 1 to 16
Fishing slopes .... 4 to 1

PHYSICAL CHARACTERISTICS.

	90 lb.	100 lb.	110 lb.	120 lb.	130 lb.	140 lb.
Actual weight pounds.........	89.96	101.49	110.36	120.87	129.64	138.52
Area of head, square inches....	3.20	3.80	4.04	4.40	4.63	4.93
Head—Per cent of total area...	36.2	38.2	37.4	37.1	36.4	36.3
Area of web, square inches....	3.12	2.25	2.49	2.69	3.02	3.28
Web—Per cent of total area...	24.0	22.6	23.0	22.7	23.8	24.1
Area of base, square inches....	3.50	3.90	4.29	4.76	5.06	5.37
Base—Per cent of total area...	39.8	39.2	39.6	40.2	39.8	39.6
Total area, square inches......	8.82	9.95	10.82	11.85	12.71	13.58
Moment of inertia.............	38.70	49.00	57.00	67.60	77.40	89.20
Section Modulus—Head	12.56	15.10	16.70	18.90	20.80	23.10
Section Modulus—Base	15.23	17.80	20.10	23.10	25.60	28.40
Ratio—M. I. to area..........	4.39	4.92	5.27	5.71	6.09	6.56
Ratio—Sec. Mod. to area......	1.42	1.52	1.55	1.59	1.64	1.70

NOTE.—While sections for 130 lbs, and 140 lb. rail are submitted, the A. R. E. Association neither considers them necessary nor recommends their use, at this time.

CHAPTER XXVIII.

RAIL SECTIONS RECOMMENDED BY THE AMERICAN RAILWAY ASSOCIATION IN 1908.

TYPE "A" SECTIONS.

DIMENSIONS. (In Inches.)

	60 lb.	70 lb.	80 lb.	90 lb.	100 lb.
Width (of base)	4	4–1/4	4–5/8	5–1/8	5–1/2
Height	4–1/2	4–3/4	5–1/8	5–5/8	6
Head, width of	2–1/4	2–3/8	2–1/2	2–9/16	2–3/4
Head, depth of	1–15/64	1–11/32	1–7/16	1–15/32	1–9/16
Web, thickness of	15/32	1/2	33/64	9/16	9/16
Web, depth of	2–29/64	2–1/2	2–23/32	3–5/32	3–3/8
Base, depth of	13/16	29/32	31/32	1	1–1/16
Fillet radia, head and web	3/8	3/8	3/8	3/8	3/8
Fillet radia, base and web	3/8	3/8	3/8	3/8	3/8
Neutral axis, distance to base	2.13	2.20	2.31	2.54	2.75
Min. web width, distance to base	2–17/64	2–13/32	2–9/16	2–29/32	2–15/16

FEATURES COMMON TO ALL A. R. A.—A. SECTIONS:

Curve of top of head....................14 inches radius
Curve of side of web....................14 inches radius
Curve of top corners of head....................3/8 inches radius
Curve of bottom corners of head and top and bottom corners of base..1/16 inches radius
Side slope of head....................1 to 16
Fishing slopes....................4 to 1
Fillets connecting web with head and base....................3/8 inches radius

PHYSICAL CHARACTERISTICS.

	60 lb.	70 lb.	80 lb.	90 lb.	100 lb.
Actual weight, pounds..........				89.96	
Area of head, square inches..........	2.21	2.68	3.05	3.20	3.64
Head—Per cent of total area..........	37.7	39.3	38.8	36.2	36.9
Area of web, square inches..........	1.41	1.49	1.65	2.12	2.29
Web—Per cent of total area..........	24.1	21.8	21.0	24.0	23.4
Area of base, square inches..........	2.24	2.65	3.16	3.50	3.91
Base—Per cent of total area..........	38.2	38.9	40.2	39.8	39.7
Total Area, square inches..........	5.86	6.82	7.86	8.82	9.84
Moment of inertia	15.41	21.05	28.80	38.70	48.94
Section Modulus—Head	6.50	8.21	10.24	12.56	15.04
Section Modulus—Base..........	7.24	9.51	12.46	15.23	17.78
Ratio—Moment of inertia to area..........	2.63	3.09	3.66	4.39	4.97
Ratio—Section Modulus to area..........	1.11	1.20	1.30	1.42	1.53

CHAPTER XXIX.

RAIL SECTIONS RECOMMENDED BY THE AMERICAN RAILWAY ASSOCIATION IN 1908.

TYPE "B" SECTIONS.

DIMENSIONS. (In Inches.)

	60 lb.	70 lb.	80 lb.	90 lb.	100 lb.
Width (of base)	3–11/16	4–3/64	4–7/16	4–49/64	5–9/64
Height	4–3/16	4–35/64	4–15/16	5–17/64	5–41/64
Head, width of	2–1/8	2–3/8	2–7/16	2–9/16	2–21/32
Head, depth of	1–1/4	1–23/64	1–15/32	1–39/64	1–45/64
Web, thickness of	31/64	33/64	35/64	9/16	9/16
Web, depth of	2–1/16	2–17/64	2–15/32	2–5/8	2–55/64
Base, depth of	7/8	59/64	1	1–1/32	1–5/64
Fillet radia, head with web	5/16	5/16	5/16	5/16	5/16
Fillet radia, base with web	5/16	5/16	5/16	5/16	5/16
Neutral axis, distance from base	1–61/64	2–5/32	2–35/128	2–57/128	2–5/8
Min. web width, distance from base	1–29/32	2–7/128	2–15/64	2–11/32	2–65/128

FEATURES COMMON TO ALL A. R. A.—B. SECTIONS:

Curve of top of head	12 inches radius
Curve of side of web	12 inches radius
Curve of top corners of head	3/8 inches radius
Curve of bottom corners of head and top and bottom corners of base	1/16 inches radius
Angle of sides of head with vertical	3 degrees
Fishing angles	13 degrees
Fillets connecting web with head and base	5/16 inches radius

PHYSICAL CHARACTERISTICS.

	60 lb.	70 lb.	80 lb.	90 lb.	100 lb.
Actual weight, pounds					
Area of head, square inches	2.28	2.76	3.07	3.56	3.95
Head—Per cent of total area	38.8	40.1	38.8	40.1	40.2
Area of web, square inches	1.14	1.34	1.54	1.70	1.89
Web—Per cent of total area	19.4	19.5	19.5	19.2	19.2
Area of base, square inches	2.45	2.79	3.30	3.61	4.01
Base—Per cent of total area	41.8	40.4	41.7	40.7	40.6
Total area, square inches	5.87	6.89	7.91	8.87	9.85
Moment of inertia	13.3	18.6	25.1	32.3	41.3
Section Modulus—Head	5.90	7.79	9.38	11.45	13.70
Section Modulus—Base	6.80	8.62	11.08	13.21	15.74
Ratio—Moment of inertia to area	2.26	2.70	3.17	3.64	4.19
Ratio—Section Modulus to area	1.00	1.13	1.19	1.29	1.39

CHAPTER XXX.

RAIL SECTIONS RECOMMENDED BY THE AMERICAN SOCIETY OF CIVIL ENGINEERS, 1893.

DIMENSIONS. (In Inches.)

	40 lb.	45 lb.	50 lb.	55 lb.	60 lb.	65 lb.	70 lb.
Width (of base).....	3–1/2	3–11/16	3–7/8	4–1/16	4–1/4	4–7/16	4–5/8
Height	3–1/2	3–11/16	3–7/8	4–1/16	4–1/4	4–7/16	4–5/8
Head, width of......	1–7/8	2	2–1/8	2–1/4	2–3/8	2–13/32	2–7/16
Head, depth of......	1–1/64	1–1/16	1–1/8	1–11/64	1–7/32	1–9/32	1–11/32
Web, thickness of...	25/64	27/64	7/16	15/32	31/64	1/2	33/64
Web, depth of......	1–55/64	1–31/32	2–1/16	2–11/64	2–17/64	2–3/8	2–15/32
Base, depth of......	5/8	21/32	11/16	23/32	49/64	25/32	13/16
Fillet radia, head with web	1/4	1/4	1/4	1/4	1/4	1/4	1/4
Fillet radia, base with web	1/4	1/4	1/4	1/4	1/4	1/4	1/4
Neutral Axis, dist. to base	1.67	1.76	1.88	1.97	2.05	2.14	2.22
Min. web width, dist. to base	1–71/128	1–41/64	1–23/32	1–103/128	1–115/128	1–31/32	2–3/64

	75 lb.	80 lb.	85 lb.	90 lb.	95 lb.	100 lb.
Width (of base)	4–13/16	5	5–3/16	5–3/8	5–9/16	5–3/4
Height	4–13/16	5	5–3/16	5–3/8	5–9/16	5–3/4
Head, width of	2–15/32	2–1/2	2–9/16	2–5/8	2–11/16	2–3/4
Head, depth of	1–27/64	1–1/2	1–35/64	1–19/32	1–41/64	1–45/64
Web, thickness of	17/32	35/64	9/16	9/16	9/16	9/16
Web, depth of	2–35/64	2–5/8	2–3/4	2–55/64	2–63/64	3–5/64
Base, depth of	27/32	7/8	57/64	59/64	15/16	31/32
Fillet radia, head with web	1/4	1/4	1/4	1/4	1/4	1/4
Fillet radia, base with web	1/4	1/4	1/4	1/4	1/4	1/4
Neutral axis, dist. to base	2.30	2.38	2.47	2.55	....	2.73
Min. web width, dist. to base	2–15/128	2–3/16	2–17/64	2–45/128	....	2–65/128

FEATURES COMMON TO ALL A. S. C. E. SECTIONS:

Curve of top of head..12 inches radius

Curve of side of web..12 inches radius

Curve of top corners of head................................5/16 inches radius

Curve of bottom corners of head and top and bottom corners of base..1/16 inches radius

Sides of head...Vertical

Fishing angles..13 degrees

Distribution of metal—Head, 42 per cent; web, 21 per cent; base, 37 per cent.

Height of rail equals width of base

PHYSICAL CHARACTERISTICS.

	70 lb.	75 lb.	80 lb.	85 lb.	90 lb.	95 lb.	100 lb.
Actual weight, pounds							
Area of head, square inches....			3.31	3.50	3.68	....	4.13
Head—Per cent of total area...	42.0	41.7	41.8	41.9	41.7	....	42.2
Area of web, square inches.....			1.66	1.75	1.85	....	2.06
Web—Per cent of total area...	21.1	21.2	20.9	21.2	20.9	....	20.5
Area of base, square inches....			2.92	3.09	3.30	....	3.63
Base—Per cent of total area..	36.9	37.1	37.3	36.9	37.4	....	37.3
Total area, square inches......	6.81	7.33	7.89	8.34	8.83	....	9.82
Moment of inertia............	19.70	22.86	26.38	30.07	34.39	....	43.8
Sec. Mod.—Head..............	8.19	9.10	10.07	11.08	12.19	....	14.55
Sec. Mod.—Base..............	8.87	9.94	11.08	12.17	13.49	....	16.11
Ratio—M. I. to area..........	2.77	3.12	3.34	3.60	3.89	....	4.46
Ratio—Sec. Mod. to area......	1.16	1.24	1.28	1.33	1.37	....	1.47

CHAPTER XXXI.

SPECIAL SECTIONS.

All railroads have not adopted as standard, the sections recommended from time to time by the various Associations; but on account of local conditions (principally of weather and traffic), use rails of such section or of such compositoin as will, in their opinion, best withstand such conditions.

Following tables show the dimensions of some well known special sections.

	136 lb. L. V.	135 lb. C. of N. J.	125 lb. Penna.	110 lb. L. V.	105 lb. Dudley	101 lb. D.L.&W.
Width (of base)	6–1/2	6	5–1/2	5–1/2	5–1/2	5–3/8
Height	7	6–1/2	6–1/2	6	6	5–7/16
Head, width of	2–15/16	3–5/32	3	2–7/8	3	2–3/4
Head, depth of	1–7/8	2	1–7/8	1–7/8	1–5/8	1–23/32
Web, thickness of	21/32	3/4	21/32	19/32	19/32	5/8
Web, depth of	3–7/8	3–9/32	3–13/32	3–1/16	3–13/32	2–11/16
Base, depth of	1–1/4	1–7/32	1–7/32	1–1/16	31/32	1–1/32
Fillet radia, head with web	1/2	3/8	1/2	3/8	1/2	1/4
Fillet radia, base with web	3/4	3/8	3/4	3/8	1	1/4
Neutral axis, dist. to base	3–1/16	2.99	3	....	....	2.50
Fishing angles or slopes	4 to 1	14 deg.	14 & 18 d.	4 to 1	4 to 1	13 deg.

	100 lb. C.&N.W.	100 lb. P. & R.	100 lb. NYNH&H	100 lb. P.S. 1908	95 lb B. &A.	91 lb. D.L.&W.
Width (of base)	5–9/64	5–3/8	5–1/2	5	....	5–3/8
Height	5–45/64	5–5/8	6	5–11/16	....	5–1/4
Head, width of	2–9/16	2–21/32	2–3/4	2–43/64	....	2–5/8
Head, depth of	1–39/64	1–45/64	1–23/32	1–13/16	....	1–41/64
Web, thickness of	9/16	9/16	19/32	9/16	....	5/8
Web, depth of	2–61/64	2–55/64	3–11/32	2–25/32	....	2–11/16
Base, depth of	1–9/64	1–1/16	15/16	1–3/32	....	59/64
Fillet radia, head with web	5/16	5/16	1/4	5/16	....	1/4
Fillet radia, base with web	5/16	5/16	1/4	5/16	....	1/4
Fishing angles or slopes	13 deg.	13 deg.	13 deg.	13-15 deg.	....	13 deg.

	90 lb. SantaFe	90 lb. Harriman	90 lb. G. N.	85 lb. Can.Pac.	85 lb. K.C.S	85 lb. Mo.Pac.
Width (of base)	5–3/16	5–3/8	5	5	4–7/8	5–1/4
Height	5–5/8	5–3/4	5–3/8	5–1/8	5–3/8	5–7/32
Head, width of	2–9/16	2–3/4	2–5/8	2–1/2	2–17/32	2–15/32
Head, depth of	1–15/32	1–1/2	1–1/2	1–7/16	1–29/64	1–3/4
Web, thickness of	9/16	17/32	5/8	9/16	17/32	75/128
Web, depth of	3–5/32	3–3/8	2–7/8	2–11/16	2–15/16	2–39/64
Base, depth of	1	7/8	1	1	63/64	55/64
Fillet radia, head with web	3/8	1/4	3/8	3/8	3/8	5/16
Fillet radia, base with web	3/8	1/4	3/8	3/8	3/8	5/16
Neutral axis, dist. to base	2.54	....	2.42	....	2.43	....
Fishing angles or slopes	14 deg.	13 deg.	13 deg.	4 to 1	14 deg.	13 deg.

NOTE: Radius of curve of top corners of head of G. N. 90-lb. rail—⅝ in.

CHAPTER XXXII.

RAIL SECTIONS IN SERVICE ON.......................R. ....19....

DIMENSIONS.

Width (of base)...............	....	....	....	....	....	....
Height	....	....	....	....	....	....
Head, width of...............	....	....	....	....	....	....
Head, depth of................	....	....	....	....	....	....
Web, thickness of............	....	....	....	....	....	....
Web, depth of.................	....	....	....	....	....	....
Base, depth of................	....	....	....	....	....	....
Fillet radia, head with web....	....	....	....	....	....	....
Fillet radia, base with web.....	....	....	....	....	....	....
Neutral axis, dist. to base......	....	....	....	....	....	....
Fishing angles or slopes......	....	....	....	....	....	....

DRILLING:

Diameter of holes	....	....	....	....	....	....
Center of holes to base	....	....	....	....	....	....
End of rail to cen. 1st hole	....	....	....	....	....	....
Cen. of 1st to cen. 2nd hole	....	....	....	....	....	....
Cen. of 2nd to cen. 3rd hole	....	....	....	....	....	....

PHYSICAL CHARACTERISTICS.

Actual weight, pounds	....	....	....	....	....	....
Area of head, square inches	....	....	....	....	....	....
Head—Per cent of total area	....	....	....	....	....	....
Area of web, square inches	....	....	....	....	....	....
Web—Per cent of total area	....	....	....	....	....	....
Area of base, square inches	....	....	....	....	....	....
Base—Per cent of total area	....	....	....	....	....	....
Total area, square inches	....	....	....	....	....	....
Moment of inertia	....	....	....	....	....	....
Section Modulus	....	....	....	....	....	....
Ratio—M. I. to area	....	....	....	....	....	....
Ratio—Sec. Mod to area	....	....	....	....	....	....

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